Assessing land conservation strategies: the case of the Florida Everglades

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ABSTRACT
South Florida's Everglades is home to 67 threatened and endangered species. By 2100 it is estimated that sea level rise will inundate over 20% of existing conservation lands. Species will be dislocated and migrate to new land. Simultaneously, more than 500,000 people are moving to the region annually. The new populations are subdividing and developing rural lands. By 2100, it is estimated that over 60% of rural land will be urbanized. In this thesis, I use Geographic Information Systems to project the location of urban land, conservation land and inundated land in South Florida over the next 50 years. I assess fee simple purchase and conservation easements as potential methods of conveying land protection. I conclude that none of the current methods of conservation have the capacity to manage the large scale land protection that will be critical in the coming years, if we are to protect our species from the emergent and significant stressors of climate change and urbanization. I conclude that a major federal initiative based on purchasing deed restrictions and a new agency that specializes in monitoring will be necessary to quickly creating a large, adaptive ecological reserve network.

Acknowledgements

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1. Introduction

In the United States, 1,954 species are federally listed as threatened or endangered (U.S. Fish and Wildlife Service 2009). Worldwide, almost 17,000 species are included on the IUCN Red List of Threatened Species (International Union for Conservation of Nature 2008). As extinction continues to accelerate, more and more environmentalists are concerned with protecting global biodiversity (Noss and Cooperrider 1994). Yet, exactly how to protect biodiversity – especially given the pressure of increasing urbanization and a finite budget for land conservation – has become a subject widely discussed in the literature.

Recognizing that not all biologically valuable land can be purchased, one of the major branches of biodiversity planning concerns the theory of nature reserve selection under constraints. Recently, publications on reserve selection are almost exclusively technical writings on such topics as the efficiency of a given spatially explicit algorithm, the use of network analysis in reserve design, or the impact of embedding mandatory sites in an optimization algorithm (Prendergast, Quinn, and Lawton 1999; Carwardine et al. 2007; Higgins, Hajkowicz, and Bui 2008). All of these optimization models, however, have several important embedded assumptions that are not clearly discussed.

Reserve selection models are comprised of several lower order models, including species models. The species models, in turn, are often the product of several components, including information on vegetative land cover. These vegetation maps are typically derived from Landsat satellite imagery. By the time the vegetation is mapped from the satellite imagery, the species models are produced and the selection algorithm is developed and run, all of the input data is often several years old. The models, therefore, optimize for a reserve given past environmental conditions.

This leads to one of the major short comings of the optimization models: the implicit assumption that existing environmental conditions are stable. This assumption is problematic given the current knowledge on global climate change. It is well documented and widely agreed upon within the scientific community that there will be global changes in air temperature, precipitation and sea level within the coming years. Such climate change will inevitably impact the spatial distribution of vegetation and, consequently, the location of species populations. As a result, a piece of land that was once biologically rich may become poor. Another area that was once biologically poor may become rich.

Recently, a few ecologists have begun to incorporate predictive species modeling into optimization analyses (Rodriguez et al. 2007). Yet, with the large and compounding uncertainties related to climate change and ecosystem response, it is increasingly more difficult to identify optimal lands for conservation for the future, despite the body of literature that is focused on this subject. Without being able to identify optimal lands with certainty, the question arises of how to ensure adequate environmental protection for species in changing landscape.

How to convey environmental protection in a changing landscape is becoming even more critical as exurban growth expands and development begins to encroach on protected lands throughout the Unites States. Where many conservation lands were once surrounded by agriculture, ranching, or undeveloped lands, developments and their associated infrastructure now abut conservation land (Theobald 2001). This fragments surrounding habitat and diminishes the ecosystem's resilience, as the species within the conservation land are limited in their ability to spatially respond to environmental changes (Forman 1995).

Rather than focusing on identifying an optimal reserve, as is popular in the literature, in this thesis I am beginning with the assumption that there is no optimal reserve design that can endure over time. Instead, I will consider how to design a flexible and adaptable reserve network that can incorporate and respond to changing environmental conditions. I will evaluate different land protection mechanisms as the agent for creating a responsive network. Using a spatially explicit model, I will determine which method of conveying protection will likely provide the most environmentally protective configuration of conservation land and urbanized land over time.

Currently, conservation land is formally protected through two different mechanisms. The first is fee simple purchase of a property. Land is bought at fair market price and managed by a conservation-oriented organization or agency. The second is a deed restriction, where the development rights of a property are severed from the land and this restriction is written into the deed of land. The development rights then are purchased and retired for perpetuity (commonly known as a conservation easement) or are traded to another area where development is encouraged (this is known as a Transfer of Development Right, or TDR). Each mechanism has known advantages and drawbacks. In this thesis, I will consider the relative merits of each.

The challenge of protecting a rapidly changing landscape that is threatened by climate change and urbanization is exemplified in south Florida's Everglades. There are currently 67 endangered species (Traxler 2009) in the Everglades and approximately 27 million people living in the 30 surrounding counties. An additional 500,000+ people are moving to the area annually (University of Florida Bureau of Business and Economic Research 2008). Furthermore, while it is still not well understood how climate change may impact Everglades habitat, it is widely agreed upon that significant amounts of land will be lost to sea level rise. By 2060, this may include up to almost 1.3 million acres of existing conservation land and 300,000 acres of existing urbanized land.[1]

[1] Methodology for calculation detailed in section 3.4.

As species and people are dislocated due to sea level rise, it is likely that the two will compete for new land in south Florida. Protection of new land will be critical to the preservation of the species of the Everglades ecosystem. Yet, the question remains of how to best identify the land that should be protected and then convey protection to that land with a limited conservation budget. Furthermore, is there a mechanism that could allow the network to adapt to new environmental conditions over time?

In this study, I will evaluate fee simple purchase and deed restrictions as methods of conveying protection to land in the Florida Everglades. I will do so by developing a conservation model that explicitly accounts for urbanization, human migration, species migration and climate change impacts when protecting land for conservation. I will then use this model to determine which land purchasing strategy creates the most environmentally protective configuration conserved land and urbanized land over time. While much of the input data for the model is preliminary, it is my hope that this model for conservation planning can continue to be upgraded and considered when making decisions regarding land protection. Similarly, while this study focuses on the Florida Everglades, I hope that this framework for evaluating conservation will be applied to other conservation projects in other ecosystems.

2. Context

The Everglades has a unique and rich ecology. It is defined by a topography that changes on the scale of inches per mile, limestone rock and ankle-deep water. The Everglades is commonly referred to as a “river of grass” due to the pervasive sawgrass stretching for acres and acres amid its slow-moving water. Yet, the Everglades is not a river with natural flow. Instead, it is a highly engineered system of canals, pumps, water storage and dikes. Every drop of water progressing through the system is minutely directed from its source until it is distributed for human consumption or it flows to sea.

Historically, fresh water flowed down central Florida’s Kissimmee River, spilled over the banks of Lake Okeechobee, and then slowly trickled southward in a vast sheet (*see Figure 1)*. The fields of sawgrass were punctuated by islands of trees and shrubs. As the water moved across the landscape, it transitioned from fresh, to brackish and eventually it met the sea in the Florida Bay. In the Florida Bay, the Everglades morphed into rich mangroves and sea grasses. As a whole, the South Florida landscape was home to myriad microhabitats and supported an extraordinary diversity of life.

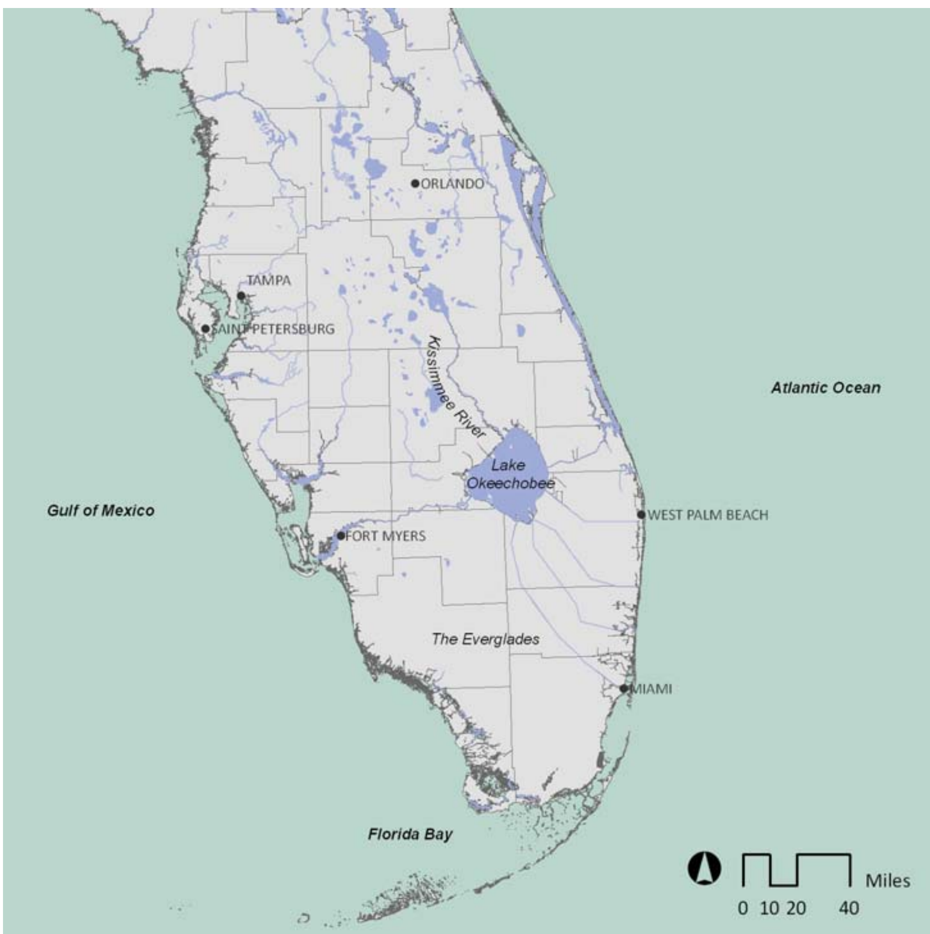


Figure 1. The location of the Kissimmee River, Lake Okeechobee and the Everglades.

Yet, as humans began to migrate to sunny South Florida, desire for flood control — both in the sense of consistent water delivery for farming and protection from hurricane-related catastrophic floods — outweighed appreciation of the nuanced ecosystem. While the natural system was prone to large seasonal variability in water availability and accepting of large floods, the new settlers needed a more predictable supply of water. The State of Florida and the United States government promoted a massive reclamation effort to dry the land and moderate water delivery. In the process, the unique hydrologic flow that defined the Everglades was destroyed and with it, much of the habitat.

To date, fifty percent of the Everglades' original wetlands have been drained or backfilled (A.L. Clark and Dalrymple 2003), almost one third of Everglades water is diverted for human use (A.L. Clark and Dalrymple 2003), there is a 90% decrease in the population of wading birds since pre-settlement times (U.S. National Park Service 2009), and there are 67 Everglades species listed as threatened or endangered (Traxler 2009). Reclamation of the Everglades has taken a significant environmental toll.

In addition the existing ecosystem threats, however, the assault to the Everglades is not finished. There are two emergent and substantial threats to the habitats of the Everglades: increasing urbanization and global climate change. Over the next fifty years, the population of South Florida will almost double.[2] Urban development and its associated infrastructure will further fragment the landscape. Global climate change is expected to significantly impact South Florida. Vegetation patterns will shift and result in landscape-level redistribution of the most valuable habitat. Some lands will be inundated by sea level rise. It is likely the most ecologically important habitat will relocate and many of the currently protected lands will loose their significance.

In the future, as species and people are dislocated and migration to Florida continues, there will be competition for South Florida's remaining undeveloped lands. This thesis explores methods of conveying protection to the Everglades and its species in a changing climate and under rapid urbanization.

2.1. Everglades history: reclamation and restoration

Through the 1800s the Everglades was perceived as an impenetrable and hostile swamp, worthy of reclamation. Conservationists of the day believed reclamation represented "wise use" of the land, believed the swamps of the Everglades were a waste of resources, and lobbied for intervention in South Florida (Grunwald 2006). In the early 1900s, after the first railroad track was laid to Miami, the federal government sponsored a major clearing and draining of the Everglades for agriculture. Levees were built around Lake Okeechobee, canals shunted water from the lake to the ocean. In the

[2] Methodology for calculation detailed in section 3.4.

early 1920s, after decades of work, residents celebrated that the Everglades were finally tamed (Grunwald 2006).

Then, in 1928 the fourth worst storm in the US's recorded history made landfall in Florida. Known as the San Felipe-Okeechobee Hurricane, it crossed the overly full Lake Okeechobee and created a six to nine foot tall lake surge (North American Atmospheric Administration 2009). The water leaped over the levee into the neighboring farmland. In its wake, the storm left 1,836 people dead and $25 million in damage (North American Atmospheric Administration 2009). Not only was it one the deadliest hurricanes in recorded US history (second only to the Galveston Hurricane of 1900), but it followed closely on the tails 1926's financially ruinous Great Miami Hurricane. It became clear that attempts at flood control in South Florida were not sufficient.

Up until that time, reclamation projects in the Everglades were awarded to private contractors. This was due to a provision of the Swamp and Overflowed Lands Act of 1850. The act secured all of the Everglades to state ownership, yet allowed for land to be sold to private companies in order to finance reclamation (U.S. Army Corps of Engineers 2009). Following the 1920s hurricanes, however, private contracting was abandoned and the US Army Corps of Engineers began to take over the job of flood control. They constructed a new dike on Lake Okeechobee, new levees and water control gates. Yet, this period of relative control was largely related to a natural dry cycle (U.S. Army Corps of Engineers 2009).

Another wet year came in 1947 and it was accompanied by two major hurricanes. Farmers' fields were flooded for months. After Hurricane Kind, total damages summed to more than $59 million (U.S. Army Corps of Engineers 2009). In response, Congress authorized the Central and South Florida Flood Control Project which provided for "1,000 miles of levees, 720 miles of canals, and almost 200 water control structures" (U.S. Army Corps of Engineers 2009). The Central and South Florida Flood Control District was established (the predecessor to the current South Florida Water Management District) and the Army Corps redoubled their efforts to dredge, channelize, backfill and dam. Thus, the groundwork was laid for the system of flood control that is still in place today.

During this time of engineering and flood control a second trend was emerging: the recognition of the natural value of the Everglades and a backlash against the human impacts on the ecosystem. In addition to being a wet, stormy year, 1947 marked the publication of Majory Stoneman Douglas's seminal work, *The Everglades: The River of Grass*. Her invocation, "The Everglades is a test. If we pass, we may get to keep the planet," was repeated nationally by environmentalists. Congress heard the national interest in the Everglades and, despite their continued support for re-engineering the region's natural hydrology, Congress established Everglades National Park, Big Cyprus National Preserve and Biscane Bay. Most significantly, Everglades NP was the first National Park designated because of its biodiversity value, rather than its recreational value (U.S. National Park Service 2009). A number of other state and private conservation lands were established following the federal precedent (*see Figure 2)*.

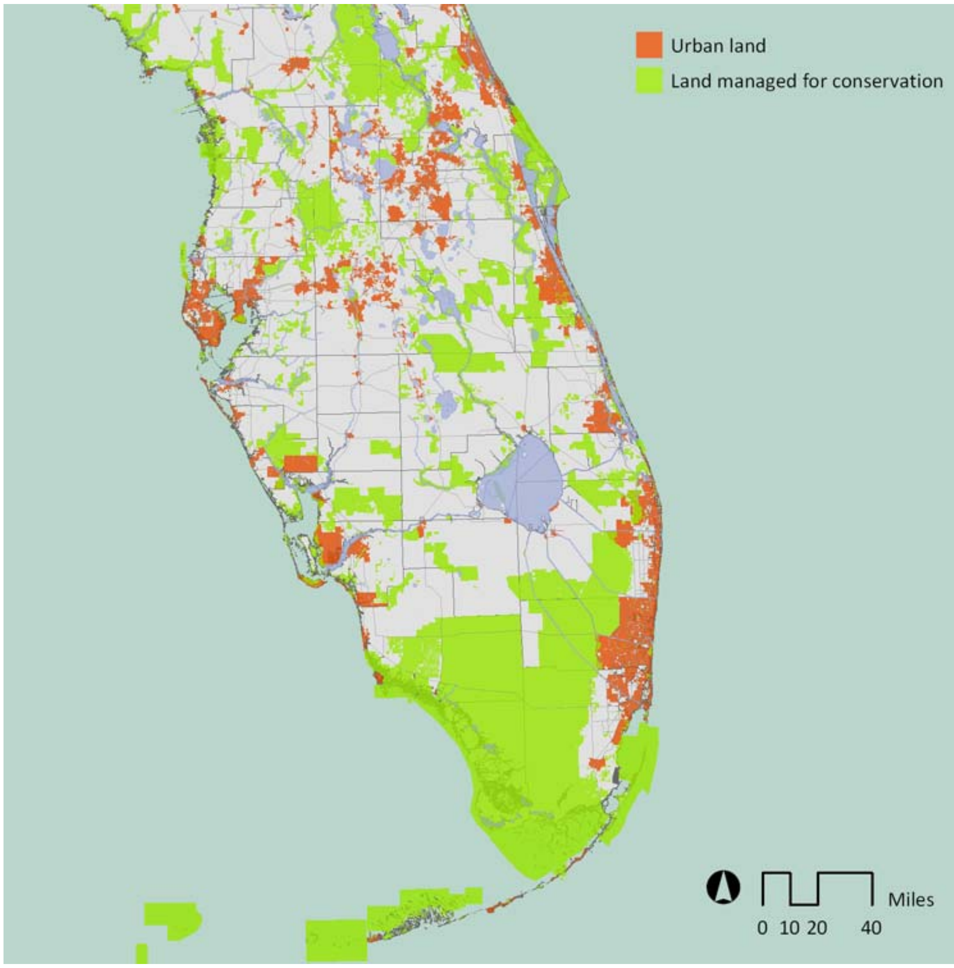


Figure 2. Relationship between Lake Okeechobee, lands managed for conservation and urban lands in South Florida. Source: Florida Geographic Data Library

Over time, the Everglades has gained increasing recognition for its biological importance. It is a UNESCO World Heritage site, an International Biosphere Reserve and a Wetland of International Importance. Despite its notoriety, however, the impacts of large-scale hydrologic engineering continue to dominate the ecosystem. Furthermore, less than half of the original 11,000 square mile extent of the Everglades is protected (U.S. National Park Service 2009). Everglades National Park represents just one fifth of the southernmost portion of the Everglades (U.S. National Park Service 2009) and is physically severed by agriculture from Lake Okeechobee, which loads the downstream water with phosphorous. The clean water that reaches the park is delivered via a mechanized system of canals and pumps after the source water is split among human consumption, agriculture and the natural ecosystem (Layzer 2008). The quality and quantity of water are not sufficient for maintaining the habitat within the park.

It is widely agreed upon by biologists that it is necessary to restore the original sheet flow to the Everglades in order to save its species. Most recently, in 2000, a new plan for Everglades management was laid out in the Comprehensive Everglades Restoration Plan (CERP), a consensus-driven plan agreed upon by several groups of stakeholders. It is a $7.8 billion dollar plan dedicated to restoration. Some environmentalists, however, do not view CERP as a restoration plan, even though it is so called. Instead, they believe it is a "multi-purpose water project…led by engineers instead of scientists, tightening human control of nature instead of removing barriers and letting nature heal itself" (Grunwald 2006, 358) and that it will "simply serve as a well-endowed water supply and flood control project subsidizing further growth and development in south Florida" (A.L. Clark and Dalrymple 2003).

The primary reason environmentalists are dissatisfied with CERP is because the plan lacks legal guarantees for the quality, quantity or timing of water distribution to the natural environment and, more specifically, to Everglades National Park. The focus of the multi-stakeholder discussion leading up to the plan and in drafting the plan itself was on "getting the water right." In terms of the plan, this meant ensuring that there was sufficient water for human consumption, agriculture and the ecosystem. While it was said that the ecosystem has equal standing with humans and agriculture, in current practice human-centric needs fundamentally dictate the quantity of water released into the ecosystem and the timing of the water flows (Sylvester 2009). As ecologist Stuart Pimm wrote, "It's not that there are gaping holes in this plan, it's that we scientists are having trouble finding even a thread of restoration upon it" (quoted in Grunwald 2006, 324).

2.2. Emerging ecosystem threats
From the Swamp and Overflowed Lands Act of 1850 to the present, the majority of debates concerning the Everglades have focused on water. As evidenced by CERP, almost all restoration plans hinge on water quantity, quality, timing and distribution. Water, however, is not the Everglades only problem.

In addition to the problems associated with water, the borders of the Everglades are not secure. As the footprint of urbanization expands and sea level rises, the spatial extent of the Everglades is pinched from all sides. The area of undeveloped and protected land within the Everglades will decline. Furthermore, the ecological value of lands will change as vegetation succession occurs, meaning that many of the presently protected lands may lose their value. If we are going to protect the species of the Everglades, it is necessary to preemptively identify lands for conservation that may become valuable habitat in the future and protect those lands before they are developed.

CERP does not adequately consider the spatial impacts of urbanization on the Everglades. It does not discuss potential mechanisms of responding to the impacts of climate change and it does not consider the combined consequences of urbanization and climate change. CERP is not alone, however. There has been no study completed to date that considers the combined affect of urbanization and climate change on the Everglades ecosystem, even though this combined assault may represent the greatest threat to the Everglades yet.

While this thesis does not discount the ecological importance of water flows in the restoration of the Everglades, the remainder of the thesis will consider the spatial arrangement of urbanized and conserved land with respect to the most basic tenants of landscape ecology (Forman 1995):

- Large patches of protected land are more ecologically valuable than fragmented lands
- Connected protected lands are more ecologically valuable than isolated lands

2.2.1 Urbanization

Between 2000 and 2007, the population of Florida grew at approximately 566,380 people a year (University of Florida Bureau of Business and Economic Research 2008). While growth has temporarily lagged in response to economic conditions, the population of Florida is still expected to double by approximately 2050.[3]

There are two recent and comprehensive, predictive studies on the future allocation of urban land in Florida. The first, a state-wide land use allocation model developed by the Resource Systems Group, examines growth by Traffic Analysis Zone (TAZ) for future highway planning. Its results are not publicly available (to prevent land speculation based on infrastructure investment). The second is funded by environmental non-profit 1000 Friends of Florida and executed by the University of Florida's GeoPlan Center. It is a component of a report entitled *Florida 2060* (2005). In this report, GeoPlan projects the allocation of urban land in 2020, 2040 and 2060 given a median projected population (also from BEBR), status quo land use policies, and continuation of existing county-wide densities. The report was widely distributed to planning departments throughout the state. GeoPlan's simulation shows almost 7 million acres of new urban land in all of Florida by 2060, representing a 116% increase over the current amount of urban land (*see Figure 3*).

[3] See methodology in section 3.4.

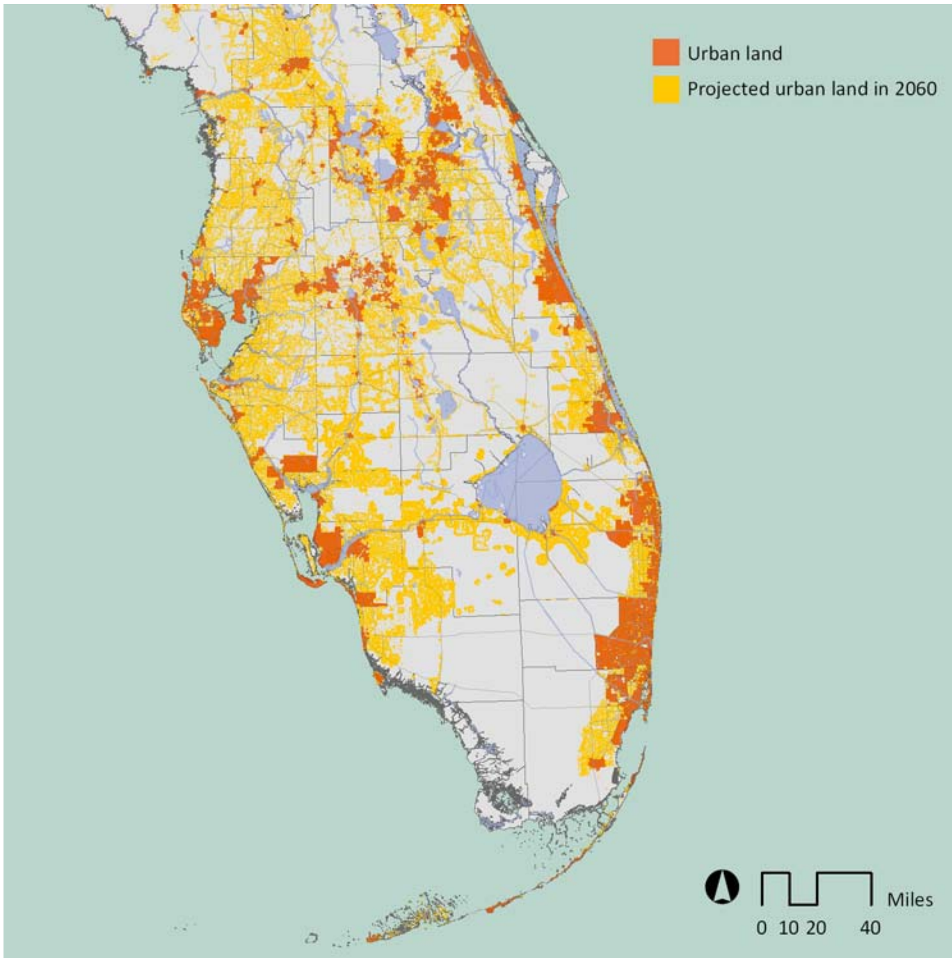


Figure 3. Projected spatial extent of urbanization by 2060, given status quo land use policies. Note that *Florida 2060* examined the whole state of Florida, but this map is focused on the study area of this thesis. Source: Florida Geoplan via Florida Geographic Data Library

The GeoPlan analysis demonstrates that, under status quo policies, urbanization has the potential spread to the south of Lake Okeechobee and to extend to the boundaries of existing protected lands. Homes, roads and commercial development will replace the existing agriculture and undeveloped lands. This will further constrict the ecosystem, limiting species' ability to spatially adapt to new stressors.

2.2.2. Climate change

The Everglades is particularly susceptible to the impacts of climate change for many reasons, including the sensitivity of the flora and fauna of the ecosystem to changes in water availability and its shallow topography.

Ecosystem response

While the local impacts of climate change are not yet well understood, it is clear that precipitation will shift in quantity and temporality, air temperature will increase, and sea temperature will increase (Stanton and Ackerman 2007; Alvarez 2003; Intergovernmental Panel on Climate Change 2007). These environmental changes will result in vegetation succession, as plants respond to the new environmental conditions. Some communities of plants will die, while new communities will form where they have not been previously observed (United States Geological Survey 1997).

At Everglades National Park, modeler and landscape ecologist Leonard Pearlstine is beginning a project to create a rule-based, state-change transition model that documents vegetation succession based on environmental inputs (Pearlstine 2009). He anticipates, for example, that there will be a salinity variable. As the value of the salinity variable increases in a particular area (as will be the case with sea level rise), the model will indicate a series of possible vegetative communities that will be tolerant of the new conditions. Combined with other factors (such as the existing vegetative community, or phosphorous loads), the model will determine the new community that will inhabit the area.

While this model is the basis for understanding how habitat will shift and how second-order species will respond, it is not yet available. More problematic is that its spatial extent will be limited to the extent of the historic Everglades, which does not include much of the western edge of the study area or most land north of Lake Okeechobee, some of which is believed to be of strong biological value (Cox and Kautz 2000). Therefore, at least for near future, there are no available models to study ecosystem-wide vegetation change in south Florida.

Without information on vegetation change, it is difficult to predict which lands may be ecologically valuable in the future. In order to provide adequate protection, it is therefore necessary to follow general principles in landscape ecology and biodiversity planning: preserve large, connected patches of land that are habitat to a diversity of species (The Heinz Center 2009).

Sea level rise

There is also not yet a peer reviewed, downscaled model for the local effects of global climate change on Florida. Nonetheless, it is certain that all of south Florida will be strongly impacted by sea level rise because of its shallow topography. The most localized information currently available is the Tufts University report *Florida and Climate Change: the Costs of Inaction*. This report cites sea level rises of 7.1 in (0.18 m) to 45.3 in (1.15 m) by 2100 (Stanton and Ackerman 2007) and is calculated based off of findings from the Intergovernmental Panel on Climate Change and supplemented by a more advanced understanding of ice sheet dynamics supplied by physicist Stefan Rhamstorf (Rahmstorf 2007).

The IPCC estimated a range of 0.18 m to 0.59 m of seal level rise by 2100. The report caveats that it does not “include the full effects of changes in ice sheet flow, because a basis in published literature is lacking” (Intergovernmental Panel on Climate Change 2007, 45). Since that time, information on ice sheet kinematics has rapidly evolved. As better information becomes available, new estimates of sea level rise are being developed. This thesis will consider the most recent values published in *Science* of 0.8 – 2.0m (Pfeffer, Harper, and O'Neel 2008). Pfeffer et al specifically state that "a total sea-level rise of about 2 meters by 2100 could occur under physically possible glaciological conditions but only if all variables are quickly accelerated to extremely high limits" (Pfeffer, Harper, and O'Neel 2008, 1340).

Figure 4 shows a spatial approximation of the impacts from rises of 0.8 (the most probable rise, as proposed by Pfeffer et al) and 2.0 m. This map of sea level rise is purely based off of elevation data and does not account for new land deposition or vegetative response to sea level rise. Nor does the map account for new flood plains. Based on straight elevation, however, almost 2 million acres of land is lost with 2.0 m of rise, displacing approximately 1.6 million people.[4]

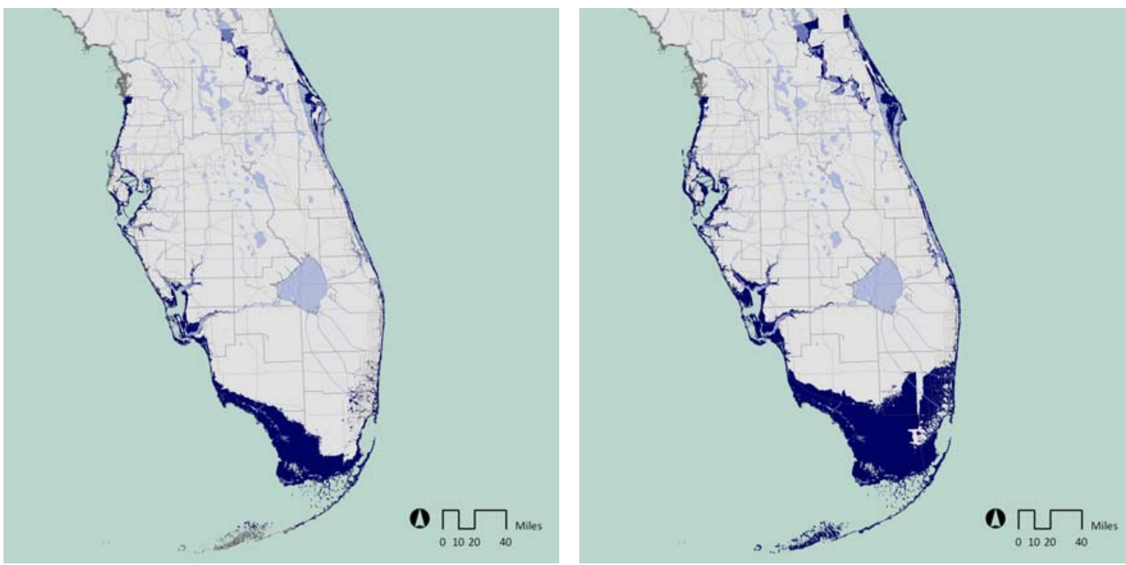


Figure 4. The extent of inundated land from 0.8 m of sea level rise (left) and 2.0 m (right)
Source: USGS DEM via FWS

It should be noted that some flooded land, in particular along the southeastern coast, will likely be protected through mitigation (e.g., seawalls). Nonetheless, sea level rise will also lead to groundwater rise in Florida and many of the inland areas will no longer be as suitable for urban uses. Additionally, increased risk of storms and associated flooding in these areas will likely lead to depopulation. Therefore, while some of these areas may not actually be inundated with sea water, in this study they are still considered to be affected by sea level rise.

[4] See methodology in section 3.3.

2.3. Land protection in Florida

To date, land protection in south Florida has been achieved through two fundamentally different mechanisms. On the one hand, local, regional and state planning bodies work towards supporting a more compact urban form via comprehensive growth management. The motivation behind growth management is largely due to the economic efficiency gains achieved by delivering services to densely developed areas. Additionally, growth management is related to protecting the economic viability of small agricultural operations (Pattison 2001). Growth management planning often has positive environmental spillover effects, but is not intrinsically related to environmental protection. On the other hand, several conservation organizations and agencies seek to protect undeveloped land for ecological gains. They typically seek purchase rural land or the development rights of the land to limit growth or dislocate intense land uses (e.g., conventional farming).

2.3.1. Comprehensive growth management

Growth management has been a part of Florida planning since the 1970s and was officially put into legislation with the Growth Management Act of 1985. Shortly there after, the state institutionalized an office of Smart Growth, created a state-wide comprehensive plan and established eleven regional planning councils (Carriker 2006).

The Growth Management Act is renewed biennially and its associated legislation tends to vary with each administration. For example, under former governor Jeb Bush, there was a stronger focus on rural economic development (Growth Management Study Commission 2001). Current governor Charlie Crist has been more focused on environmentally-minded legislation, including a refinancing of the state's Florida Forever conservation land acquisition program for the next ten years. In general, however, the State Comprehensive Plan is mandated to "provide long-range policy guidance for the orderly social, economic and physical growth of the state" (State of Florida 2009). The State also mentions, however, that the policies within the plan "may be implemented only to the extent that financial resources are provided" and "shall be reasonably applied were they are economically and environmentally feasible," leaving a fair amount of room for the plan's interpretation (State of Florida 2009).

Every county in Florida is required to implement a comprehensive growth management plan that reflects the broader goals of the Growth Management Act. Each county's comprehensive plan is submitted to their regional planning council for review. The council evaluates whether or not the county plan aligns with the state objectives. The regional planning councils may offer suggestions for the plan, but they cannot require any changes.

Each county approaches the comprehensive planning process differently. Some counties are more aggressive about growth management than others. Examples of two growth management tools used by counties in their comprehensive plans are Transfer of Development Rights and Urban Development Boundaries:

Transfer of Development Rights

Some counties have chosen to fold Transfer of Development Rights (TDRs) into their comprehensive plans (also known as Transfer of Density Units). This requires the county to designate a particular area as a "sending" area and another as a "receiving" area. Development rights are transferred from the sending area to the receiving area. Collier County, for example, has established a particularly successful TDR program in their Rural Fringe Mixed Use (RFMU) District. In their program, lands of highest ecological value are designated as sending areas and those of lowest ecological value are designated as receiving areas (Collier County 2009).

There are many different ways in which a TDR program can be formulated, but most typically they transfer density (Rick Pruetz and Erica Pruetz 2007). In other words, a land owner in the sending area forgoes the right to build to their maximum allowed density, and sells their development rights to developers in the receiving area. The developers in the receiving area, because they are using TDRs, are then allowed to build at densities beyond their current zoned maximum. For example, in Collier County, the present zoned density in the RFMU District is 1 unit per 5 acres. In the receiving areas, a developer may build up to 1 unit per acre if they purchase TDRs. As a result, the Collier County TDR program promotes a more compact urban form and limits development and land speculation in the sending areas.

Support for TDRs are seen at the state level in the Growth Management Study Commission's report from 2001. In their words, "Florida lacks a comprehensive growth management policy, which proactively and realistically addresses both the pressures of population growth and the unique characteristics and multiple needs of rural Florida" (Growth Management Study Commission 2001, 43). The commission recommended for the state to "acquire development rights or permit the transfer of those rights from lands intended to remain in agriculture in the long term, allowing landowners to reinvest payments for those development rights in the rural economy" (Growth Management Study Commission 2001, 44).

From this recommendation, the 2001 Florida Legislature created the Rural Land Stewardship Area program (Florida Statutes, Section 163.3177(11)(d)) . The RSLA program encourages counties to designate RSLAs within their border. In conventional TDR terms, the RSLAs are receiving areas. The remaining rural land in the county is the sending area. RSLAs have been implemented in several counties throughout the state. The RSLA program was recently critical in the establishment of the Florida Panther Protection Program (FPPP), a partnership between Collier County, several different developers and several conservation organizations. FPPP seeks to preserve 2.5 million acres of land, creating a corridor between Florida Panther National Wildlife Refuge and Big Cypress National Preserve, as it simultaneously develops several new, clustered towns (Florida Panther Protection Program 2009).

As evidenced by FPPP, TDRs can have positive environmental ramifications. When initially beginning this thesis, I was hopeful that TDRs could have a significant role in conservation of rural lands throughout the Everglades. There is a flaw associated with TDRs, however, that prevents them from being a successful large-scale rural conservation tool. Namely, for a TDR program to work successfully there must be a demand for the density being traded in the program (Rick Pruetz and Standridge 2009).

In Florida, almost all urban areas are not currently being built out to their maximum density. Developers could build at a higher density, but they do not choose to for economic reasons. Therefore, there is no incentive to purchase density credits in most urban areas. To make a density transfer viable, it would first be necessary to downzone the area, a process which is politically painstaking. As a result, in Florida it is currently only realistic for a density-based TDR program to be implemented within rural lands, where the zoning is most often 1 unit per 5 acres. While the ecological value of trading densities between rural lands is worth further consideration, due to the complexities of modeling an intra-rural TDR scheme, TDRs are not considered further in this study.

Urban Development Boundary

Several counties in Florida have relied upon an urban service boundary or an urban development boundary (UDB) as a means of growth management. The UDB is often adaptable, but generally demarcates the extent to where services such as water and sewer will be extended. Several of Florida's UDBs are criticized for being too amenable to change (Clean Water Action 2009), but price-effects demonstrate that the UBD makes development significantly more difficult outside its boundary. In Miami-Dade County, the average assessed value of parcels within the UDB is \$3.38/sq ft while the average assessed value outside of the UDB is \$0.18/sq ft (Bernknopf et al. 2009). Not surprisingly, farmers whose property abut the UDB are often fighting to have the UDB altered to include their property (Bernstein 2007).

While the UDB has the positive environmental effect of concentrating development, the UDB is not considered further in this study because it does not formally convey protection status to any land. It is possible, however, that UDBs could offer the most flexible means of informally keeping land undeveloped. The value of formality in conservation planning is worth further consideration.

2.3.2. Land and development right acquisition

Many pro-conservation organizations and agencies protect Everglades land through fee simple purchase and conservation easements. To date, fee simple purchase has been their primary means of conveying protection, with the establishment of large federal parks and preserves. Conservation easements in the Everglades have historically been limited to smaller parcels.

Fee simple purchase
Many different groups are involved in fee simple purchases. Many local governments convey environmental protection by fee simple purchase of conservation lands, as does the State of Florida, several federal agencies and land trusts.

In 2000, the Comprehensive Everglades Restoration Plan (CERP) was enacted with a $7.8 billion, 30 year budget (A.L. Clark and Dalrymple 2003), the largest budget ever assigned to a conservation project. The new budget enabled extensive biological research and funded critical land acquisitions. In 2008, the high-profile purchase of US Sugar was negotiated for $1.3 billion, an agreement widely hailed by environmentalists and critical to the re-establishment of the historic hydrology of the Everglades. While this agreement is currently being whittled down in price and acreage (Hafenbrack and Reid 2009), the US Sugar acquisition would still be a significant environmental gain.

Additionally, the Florida Forever program within the State of Florida's Department of Environmental Protection has protected over 500,000 acres of land and spent approximately $1.8 billion since its inception in 2001 (Florida Department of Environmental Protection). The program is funded at $300 million per annum (State of Florida 2009) and its budget was renewed for the next ten years by Governor Crist in January, 2009 (1000 Friends of Florida 2009). It should be noted, however, that this budget has not yet been written into the appropriations bill by the Florida Congress for 2009-2010. At this point in time, it is uncertain if Florida Forever will be funded.

Conservation easements
Several national organizations engage in conservation easement purchases in the Everglades, including Trust for Public Lands, The Nature Conservancy, Audubon and Defenders of Wildlife. The majority of these parcels are fairly small, though the aggregate effect has been more significant.

According to Charles Lee, the Directory of Advocacy at Florida Audubon, conservation easements in South Florida can be secured for anywhere from 50-80% of the market value of a parcel. It is more common for easements to cost closer to 50%, but in the past South Florida Water Management District purchased "flowage easements" for up to 80% of market price (Lee 2009).

It is clear that the full range of benefits that can be provided by conservation easements have not yet been maximized in the Everglades. For example, it is documented in Florida that ranching is compatible with Florida Panther protection (one of the 67 threatened and endangered species) and severing the development rights from ranching land may help keep small ranchers in business and protect the panther. Yet, there are not many ranches holding conservation easements.

It is likely that a program similar to that seen in the Malpai region of New Mexico and Arizona could be successful for ranchers in Florida. In the Malpai, a group of neighboring ranchers, together called the Malpai Borderlands Group, put 75,000 acres of contiguous land under easement in order to maintain their livelihood in the face of development (Malpai Borderlands Group 2009a). The Malpai Borderlands Group transformed from a traditional ranching community into a group collectively managing their land, restoring native grasses, beginning a regiment of prescribed burns and seeing reintroduction of endangered species (Malpai Borderlands Group 2009a). Prior to the formation of the group, much of the habitat of the area was degraded. Now, on-site monitoring demonstrates significantly improved ecological conditions (Curtin 2002). The management of this land is almost entirely executed by the ranchers who work on site with partnership and external advising from the National Resource Conservation Service and the US Forest Service (Malpai Borderlands Group 2009b). Such types of community-based easements have not yet been realized in Florida ranching.

Additionally, while most conservation easements are retired in perpetuity, it is possible to craft a deed restriction in such a way that it does not convey permanent protection. With a temporary deed restriction, residents may buy back the easement from the holder under specific circumstances (Rick Pruetz and Erica Pruetz 2007). For example, in Mesa County, Colorado land owners commit to 40 year deed restrictions. This program was developed to alleviate farmer's fears that they would take on a deed restriction, their neighbors would subdivide, and they would be stuck on a farm between big box stores. With a temporary deed restriction, the farmer can choose to reevaluate his decision over time. Similarly, a temporary deed restriction may be especially useful for conservation organizations issuing easements in a changing climate. Once the temporary easement expires, the conservation organization supporting the easement can reevaluate if the land still meets their easement standards. This is similar to an arrangement in the town of Hatfield, Massachusetts, where farmers have the option to buy back their deed restrictions if the Massachusetts general court determines that their land is no longer valuable for farming.

While a temporary easement is not explored within the modeling of this thesis, its implementation could ensure that new conservation purchases remain relevant over time and that old purchases which have declined in ecological value have the potential to accommodate new urban growth. Supporting new urban growth in conservation land that has lost its biological importance may help divert development from other areas that are becoming increasingly more important.

Lastly, conservation easements are not typically held by federal agencies in Florida or elsewhere. Yet, in Florida there are some current examples of federal agencies promoting and facilitating deed restrictions. For example, George Dennis, an ecologist with the US Fish and Wildlife Service, recently established an endangered species mitigation bank where developers in urban areas can purchase mitigation credits from rural lands. For a rural landowner to qualify to be part of the banking, Dennis must have identified the land as ecologically valuable (based off of FWC GIS data and other primary sources), the owner must take on a deed restriction that ensures the sold mitigation is protected in perpetuity, and then Dennis must monitor the land to ensure that it is managed as promised over time (Dennis 2009).

Both community-based ranching easements and temporary deed restrictions are examples of creative deed restrictions that are likely useful to explore further. It is possible that creative deed restrictions could help build support for easements across a wider range of constituents. Similarly, federally supported easements may help engage a wider group of constituents, as they may establish trust and recruit people who do not commonly engage with conservation organizations.

2.3.3. Payment for Ecosystem Services

Payment for Ecosystem Services (PES), also known as Payment for Environmental Services, conveys protection to land by compensating the land owner for the economic value of the environmental service their land produces. While popular in several other countries (e.g., Costa Rica, Mexico), PES is only beginning to gain traction in the United States. In Florida, a PES program has recently been implemented in the northern Everglades around the Kissimmee River basin (Bohlen et al. 2009)b.

PES is attractive for several reasons. Namely, it provides economic incentive for a landowner to keep their land in a natural condition and may forestall development. Furthermore, PES provides incentives to landowners to deliver environmental services without proscribing the exact method of conveyance. In theory this will encourage innovative and efficient means of delivery (Sabman and Stephenson 2007). Near the Kissimmee River, PES has been helpful in providing water storage on ranchland. Land owners agree to 3 year contracts with fixed annual payments for water storage services (Bohlen et al. 2009). In exchange, land managers rehydrate wetlands, treat pasture water and collect stormwater (World Wildlife Fund 2008).

There are several downsides to PES, however. Firstly, it can be very difficult to establish the correct economic value for an environmental service. Secondly, it is challenging to ensure that the promised service is being fulfilled by the landowner and that the level of service is consistent with their degree of compensation (Bohlen et al. 2009; Balvanera et al. 2001). Thirdly, it is difficult to embed PES in our current framework of environmental regulations (Bohlen et al. 2009). For example, if an endangered species returns to a rehydrated wetland, is the landowner then responsible for maintaining the habitat on their land beyond the 3 year contract? Lastly, PES is suited to environmental conservation when there are direct anthropogenic benefits (Balvanera et al. 2001). If land is being protected for species habitat instead of flood control it will be more difficult to establish correct market prices and monitor the services provided.

Lessons learned from PES may be useful in creating more creative conservation easement agreements since PES excels at providing different kinds of protection than most existing easements. For example, it may be possible to generate temporary conservation easements for water storage. Due to the general difficulties of implementing PES as a means of species protection, however, PES is not considered in the modeling within this thesis.

2.4. Predictive modeling for Florida planning

There are many different organizations throughout the state that are involved in various forms of predictive urban and conservation modeling. This thesis builds off the methodology and outputs of several of these different models.

2.4.1. Population modeling

The Bureau of Economic and Business Research (BEBR) at the University of Florida is the state's primary center for population studies. In addition to examining the most recent census data and providing intermediate estimated populations, BEBR provides projective population on a county-by-county basis out to 2035. Their projections are based on known birth, death and migration rates (Smith and Rayer 2008). Data for the 30 counties in the study area is available in Appendix 1.

2.4.2. Urban growth modeling

The GeoPlan center at the University of Florida's College of Design, Construction and Planning is home to a significant amount of the modeling that is being done in the State of Florida. Much of the work of the GeoPlan center is generously shared with the public. I relied on the methodology for *Florida 2060* as a baseline for building the urban growth model used in this thesis (detailed in Section 3). Despite the existence of some more complex urban growth models, I referenced *Florida 2060* because of its use of state-wide datasets, its penetration in the planning community and its simplicity.

Florida 2060 considers the spatial pattern of urban growth over the next 50 years for the whole state of Florida. It does so by spatially allocating BEBR projected population data on a county by county basis at 20 year time steps. It is assumed that the current county-wide population densities remain constant over time.

To determine the locations within each county where people should be allocated, GeoPlan first constructed an urban suitability surface. Following are the criteria used in the analysis:

Urban Suitability Criterion	Rational for Use	Weight
Proximity to existing urban areas	New urban development tends to occur in close proximity to existing urban development.	29%
Presence/absence of wetlands	The presence of wetlands tends to increase the cost of urban development.	18%
Road density	New urban development tends to occur in areas of relatively higher road density.	14%
Proximity to coastline	The coast has historically been an attractor for urban development.	11%

Developments of Regional Impact (other than urban infrastructure projects like airports) and the West Bay Detailed Specific Area Plan (less the approved airport site)	Areas within approved DRIs and DSAPs are highly likely to develop. The only DSAP that was used, however, was West Bay in Bay County, because the other existing DSAPs fell in the path and pattern of new urban development and their boundaries did not affect the pattern or timing of new urban development.	10%
Proximity to major roads	Roads facilitate new urban development	7%
Proximity to centroids of major urban areas (population greater than 30,000)	Major urban areas tend to accommodate more additional population than do smaller urban areas	7%
Proximity to open water	Access to the view of water has historically been an attractor for development.	4%

Table 1. Input layers and their relative weights in the *Florida 2060* urban suitability analysis (Zwick and Carr 2006, 23).

For each time step, GeoPlan allocated the projected population of each county to the most attractive cells within the county at the county-wide density. As some counties reached maximum build-out (e.g., Broward), the remaining population was allocated into adjacent counties.

In *Florida 2060*, county density was calculated by dividing the existing population by the land area of the county to determine the number of people per square mile. As the authors discuss in an associated report, the even density assumptions led to distortion in the allocation (Zwick and Carr 2006). Namely, Miami-Dade County appears to hold a substantial number of residents at a relatively high density from border to border. Due to the density of the Miami metropolitan area, currently it appears that the whole of Miami-Dade county will build to a relatively high density. In actuality, it is unlikely that it will build out as projected.

2.4.3. Real estate value modeling

At the USGS in Menlo Park, California, Richard Bernknopf and others are working on a hedonic pricing model for Miami-Dade County. The model is a parcel-level analysis that is calibrated with 24,224 real estate transactions (Bernknopf 2009). There are 38 variables that influence the output of the model (Bernknopf et al. 2009).

It is interesting to note that when the hedonic pricing model was calibrated against actual real estate sales in Miami-Dade, it was found that parcel size did not substantively impact a parcel's valuation (Bernknopf et al. 2009). Therefore, while a parcel-based analysis is more accurate than the raster representation I will use in this thesis, raster analysis is more relevant than in localities with a skewed relationship between parcel value and parcel size.

The Miami-Dade real estate pricing model was originally built with the aim to economically quantifying the ecosystem services provided by Everglades National Park and Biscayne Bay National Park. There are now hopes to expand the study area to include Broward County and Palm Beach County. There are also plans to begin modeling the impact of sea level rise on real estate pricing in these counties.

2.4.4. Strategic habitat modeling

To help guide conservation land purchasing at the state level, scientists at Florida Fish and Wildlife Conservation Commission delineated Strategic Habitat Conservation Areas in 2000 (Cox and Kautz 2000). The dataset is currently used by Florida Forever, the state land conservation purchasing program, and others to help guide purchasing decisions.

Strategic Habitat Conservation Areas are defined based on biodiversity, hydrology, and landscape classification. They are areas that are currently unprotected that are critical for the persistence of 124 rare and imperiled species of wildlife (Cox and Kautz 2000). The SHCAs are believed to represent the *minimum* amount of habitat required for long-term species persistence (Cox and Kautz 2000).

3. Methodology

Predictive, spatial modeling allows for visualization of numerical data as maps. In this study, I will execute a series of spatial allocations in order to simulate urbanization, conservation and sea level rise in south Florida over the next 50 years.

As in *Florida 2060*, I will run my model with 20 year time steps, for the years 2020, 2040 and 2060. I will assume a fixed budget for purchasing conservation land, continued population growth, and a rising sea. As in *Florida 2060*, an urban suitability map will determine where people live and develop in the future. A conservation suitability map will determine which conservation lands should be protected.

A full diagram describing the whole model is available in Appendix 2. The rules used in making each component of the model are outlined below.

3.1. Extent and resolution

This study looks broadly at the greater Everglades ecosystem and exogenous impacts to the ecosystem. Most Everglades models and maps to date deeply describe small pieces of the ecosystem. Instead, I am choosing to sacrifice depth of analysis in exchange for a larger breadth. In doing so, I am able to consider the Everglades as one, large system.

3.1.1. Study area boundary

The area of this study includes the 30 southernmost counties in Florida. My objective was to limit the study area to the smallest extent possible while adequately including the most significant areas of impact to the greater Everglades ecosystem.

I initially formulated a boundary that closely adhered to the limit of wetlands of the Everglades, but later decided it was necessary to consider a larger number of coastal inhabitants and the population of the Orlando area. I viewed these two factors as important because as individuals are displaced from the coast it is likely that many will relocate to inland areas, including Orlando and the adjacent Kissimmee River valley. Additionally, Orlando is expected to be a site of major population growth in the future. As a result, the northern edge of my final study area boundary is defined by the counties that intersect Orlando and those that extend to the coast to Orlando's East and West (see Figure 5).

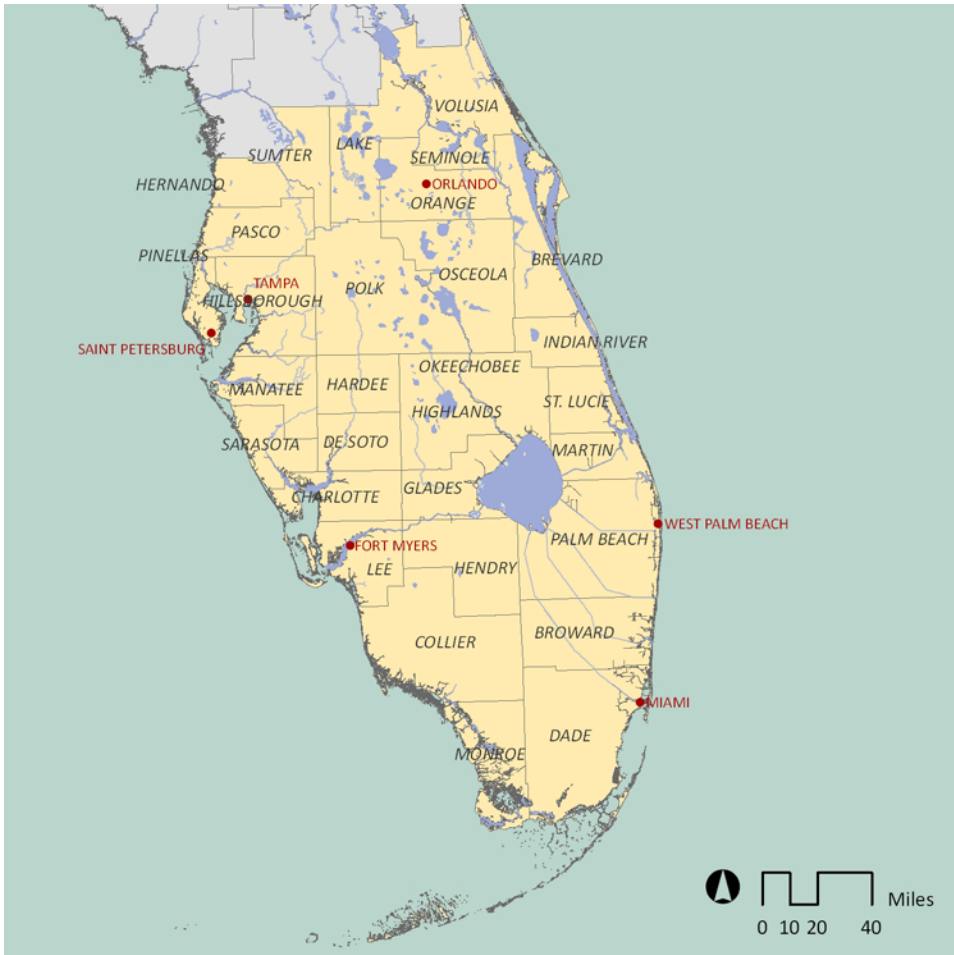


Figure 5. The thirty south and central Florida counties included in this study. Major cities shown in red.

3.1.2. Resolution

This study is executed using raster GIS analysis techniques. Every input is described by a raster with cells that are 90 meters by 90 meters, or approximately 2 acres. While a finer resolution raster analysis or, ideally, a parcel-based analysis would produce more accurate allocations, given the available data, broad spatial extent and timeframe of this study, it was necessary to perform a coarser scale raster calculation.

3.2 Restricted land

Within the study area, there are several types of land that should not be considered in the allocation because they are unavailable for either new urban development or conservation. These lands are identified as "restricted" and are masked out of all of the analyses below. Restricted lands include:

- American Indian land
- Water (including land inundated due to sea level rise)
- Existing conservation land
- Existing urban land

In this study urban land is defined by a combination of two different data inputs: US census block group data (with a population greater than 1 person per acre) and areas listed in the GAP analysis dataset with a land cover of urban, recreation or asphalt/pavement. This was roughly based of the *Florida 2060* which defines urban land as all land that supports existing urban uses including "residential, office/commercial, retail, industrial, roads, urban parks, utilities and utility corridors, golf courses, cemeteries and airports" (Zwick and Carr 2006, 5).

By masking out existing conservation land and urban land, this study focuses on rural, undeveloped land that has potential to be developed or purchased for conservation.

3.3. Population studies
To understand where people currently live and where people will likely live in the future, it was necessary to examine population trends in the study area and consider the density of future development.

3.3.1. Population projections
Following the methodology put forward in the *Florida 2060* report, I used the projected population data provided by BEBR for the 2020 scenario, and then extrapolated the population trend line out for an estimated population at 2040 and 2060. I deviated from the methodology of the *Florida 2060* report in one significant way, however. Rather than considering population growth per county, I aggregated the combined growth of the 30 counties in the study area. I felt this was a more accurate representation of how growth will proceed in the future, as some counties will reach maximum build-out, some counties will be more susceptible to the impacts of sea level rise, and other counties will then accommodate their would-be growth.

3.3.2. Population density
Seeking to create a more nuanced build-out projection than the county-wide density assumptions in *Florida 2060*, I examined population data by US census block groups. Using the most recent census data (2008 estimates), I determined density by dividing the number of residents in a block group by the total land area in the block group.

To consider future densities, I allocated the density of a given block group to its nearest non-urban neighboring areas. In my analysis, non-urban is defined by a population density less than or equal to 1 person/acre (which roughly translates to 1 household every 2.5 acres). In other words, in my study, a non-urban area will develop at the same density of the adjacent urban area.

3.4. Sea level rise approximation
There are a wide range of estimates on the potential for sea level rise and the predictions are rapidly changing with factors including global carbon output and

improved models of glacial melting. There are substantial degrees of uncertainty and it is unlikely that any of the published estimates are definitive.

For the purposes of this thesis, I will rely on the maximum rise of 2.0 meters put forward by Pfeffer et al in *Science* in September 2008. I am using this figure primarily due to its recent publication date and the reputation of *Science* for publishing high quality research. I am using the maximum figure that Pfeffer et al suggest to build a better understanding of the potential impacts of sea level rise.

Because this study extends to 2060, not 2100, I linearly calculated rise as a fraction of the total rise of 2.0 meters by 2100. This leads to the following sea level rises:

- 2020: 0.3 m
- 2040: 0.7 m
- 2060: 1.1 m

3.5. Urban suitability analysis

To determine which areas of south Florida are likely to develop in the future, it was necessary to create a continuous raster surface that represents attractiveness for urban development. Each cell was given a ranking on a scale of 1 to 5 (where 5 is the most attractive). The surface was created via a weighted overlay with a mask removing the restricted areas (details of the weighting schema are available in Appendix 3). The following layers were used in determining attractiveness for urban development:

- Proximity to centroid of urban area
- Proximity to centroid of major urban area
- Proximity to ocean
- Proximity to major road
- Presence/absence of wetlands

These factors were chosen based upon inputs used in *Florida 2060* and in the TAZ study executed by Resource Systems Group.

Four of the five factors are assumed to be constant over the timeframe of this study: proximity to an urban area, proximity to a major urban area, proximity to a major road and presence/absence of wetlands. The fifth factor, proximity to ocean, is recalculated in each time step. Despite the potential hazards of being closer to a rising ocean, in this study it was assumed that it is always more attractive to be closer to the ocean because of the possibility of mitigation.

3.6. Real estate value

The output of the urban suitability analysis was calibrated against the USGS Miami-Dade hedonic pricing model. The urban suitability analysis is broken into 5 major classes, however, while the Miami-Dade model is a continuous surface. As a result, it was necessary to convert to Miami-Dade model into 5 major price classes. Because the model was only available via an interactive on-line map (and not for download and my own manipulation), it was necessary to approximate the 5 major pricing categories.

3.7. Conservation suitability analysis

In this thesis, I relied on the Strategic Habitat modeling completed at Fish and Wildlife for the boundaries of the most important areas for conservation in south Florida (Cox and Kautz 2000). Under climate change, however, these areas will likely migrate. As a result, it is necessary to create a continuous surface of conservation suitability instead of isolated patches.

Because there is no successional conservation model currently available (and generation of such a model is beyond the scope of this study), I created a continuous conservation surface using the following layers (the weighting scheme is available in Appendix 4):

- Florida Fish and Wildlife Conservation Commission (FWC)'s designated Strategic Habitat Conservation Areas
- Biodiversity value
- Undeveloped land (natural land cover)
- Agriculture

As with the urban suitability analysis, the resulting surface ranks land on a scale from 1 to 5, where 5 is the most valuable for conservation.

3.8. Conservation land allocation

The conservation land allocation required identifying a budget and then outlining a purchasing strategy to use when deciding between land that were ranked with equal conservation value in the conservation suitability analysis.

3.8.1. Yearly budget

In this study, I assume that there is a fixed annual budget for land conservation aggregated to 20 year time steps. The full budget is spent in each time step.

My assumed budget for conservation is $300 million per annum, the existing annual budget of the state's Florida Forever land acquisition program. While it has not yet been officially renewed this year, due to occasional federal infusions of money, I assume gross decadal averages translate roughly to $300 million.

3.8.2. Purchasing strategy

In purchasing, there is often a trade-off between buying the best pieces of land and maximizing the acreage of land purchased. This study will attempt to purchase the best land in the largest contiguous patches, while avoiding the most expensive areas. To do this, I will

- Extract the land that is in the top 1% of the conservation suitability analysis
- Identify patches of conservation land that are larger than 50 acres (the minimum patch size in this study)
- Determine the real estate value of each patch of potential conservation land from the real estate value surface
- "Purchase" the least expensive, largest patches until the full yearly budget is exhausted
- The real operating budget is determined by multiplying yearly budget ($300 million) by multipliers that account for:
    - Transaction costs
    - Discount rate (fee simple purchase or a deed restriction)

To select between conservation lands of equal value, I relied on the landscape ecological principals of connectivity and patch size by delineating paths between existing conservation lands that ran through the highest value areas on the conservation suitability map. The contiguous cells of equal cost can then be grouped into patches before purchasing.

With each time step, the corridors and patches are reassessed based upon the new lands that are added to the existing conservation lands.

One of the major assumptions behind the purchasing strategy is that for each time step conservation land is secured first and urban land is determined afterwards. This is a considerable simplification relative to transaction-based real estate models.

3.9. Conservation scenarios

In this study, I consider fee simple purchase and conservation easements as methods for conveying protection to land for conservation purposes. The assumptions used to simulate each of these protection strategies in the allocation analyses are outlined below.

3.9.1. Fee simple purchase

- The transaction cost of a purchase is estimated at 6% of the real estate value of the land, based on informal conversations with several real estate brokers. Transaction costs may be as much as twice as large, so 6% is a conservative estimate.
- When land is "purchased," the number of displaced people from that land is calculated from the density raster.
- 75 % of the displaced people are assumed to remain in south Florida, while the remaining 25% relocate to outside the study area. This figure is based upon

gross assumptions that most people will chose to relocate near to their existing residence.

- The number of people who remain in the study area (75% of all displaced people) are added to the total number of projected people in the general urban land allocation.

3.9.2. Conservation easements

- The cost of a conservation easement is 50% of the real estate value of the land (Lee 2009).
- The transaction costs are estimated to be 6% of the purchase price, based on information that transaction costs were roughly equal for a conservation easement and fee simple purchase (Lee 2009).
- No people are displaced

3.10. Urban land allocation

To determine how many new people must be accommodated within the study area each year I totaled:

- The projected number of people moving into the area
- The number of people displaced by sea level rise
- The number of people (if any) displaced by conservation land purchasing

I will then allocate people to the land most attractive for urban development. The number of people that are accommodated in each cell is determined by the density raster. The allocation continues until all of the new population is located in the most desirable available land. When deciding between areas of equal desirability, people are allocated to the cell closest to existing urban areas. If two cells were of equal attractiveness and equal proximity to an existing urban area, the cell that accommodated the most people (i.e., the densest area) was populated first. For this reason, this analysis shows a more conservative estimate of spatial growth.

4. Results

4.1. Population density allocation

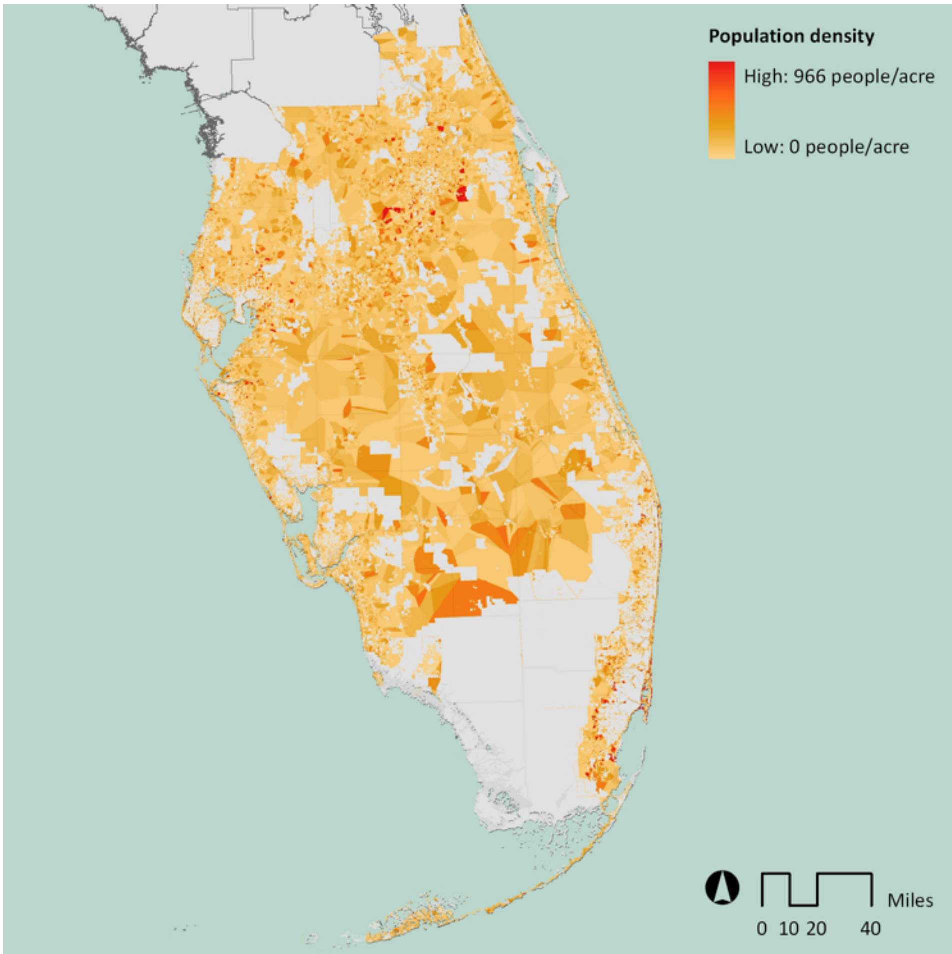


Figure 6. Potential population density allocation.

After masking out the non-urban areas (population <= 1 person/acre), I allocated the density from the 2000 census data in the urban areas across the adjacent non-urban cells. This methodology initially produced false highs in some of the rural areas in the center of the state because a small dense block (e.g., a trailer park) was allocated over a large area, as there were no other close neighbors from which the allocation could be determined. To eliminate these false spikes, I removed all densities greater than 15 people/acre from everywhere in the study area outside of existing large metropolitan areas. Areas with a density great than 15 people/acre only exist in the urban areas of Orlando, Miami, Tama-St. Petersburg, Sarasota-Bradenton, Orlando and Kissimmee.

4.2. Urban suitability

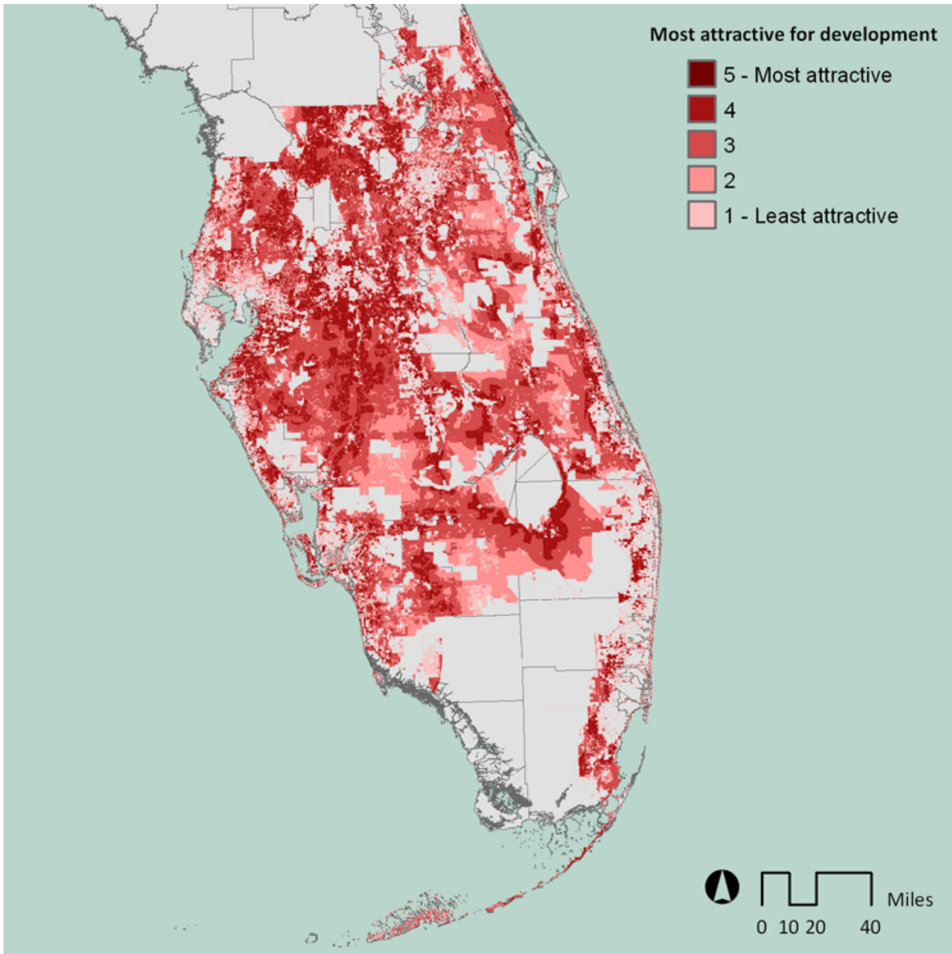


Figure 7. Existing attractiveness for urban development.

The weighted overlay resulted in a categorical breakdown where the vast majority of Florida land falls into the median class 3. Less than a total of 2% of all available land is in the most desirable and least desirable categories. This normal distribution is likely a reasonable depiction of the study area.

Class	Area (acres)	Percent of study area
5	10,276	<1%
4	2,451,085	13%
3	4,462,196	24%
2	1,785,196	9%
1	194,964	1%

Table 2. Area of land in each class of the urban suitability mapping.

4.3. Real estate value

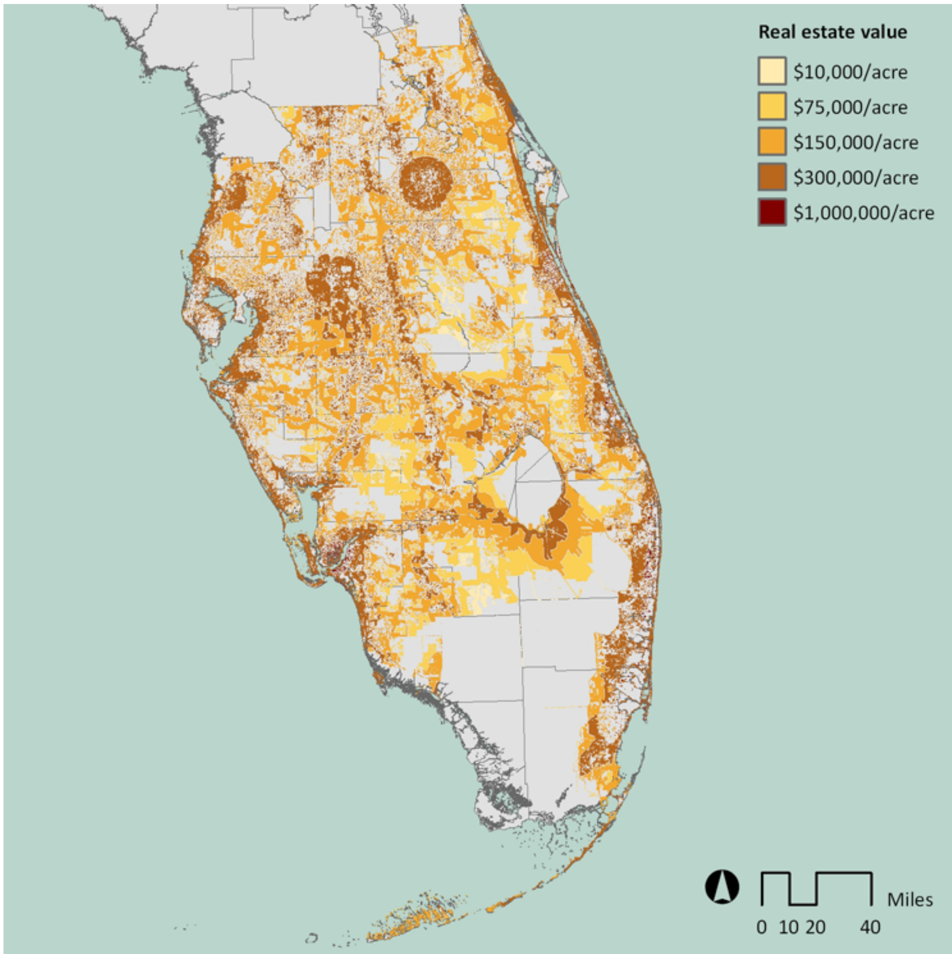


Figure 8. Approximated real estate values

After calibrating urban suitability with the USGS hedonic pricing model (Bernknopf et al. 2009), the normal distribution of pricing is maintained. Again, this distribution is probable for the area, where the majority of the land is valued in the median category of $150,000 per acre.

Land price (per acre)	Area (acres)	Percent of study area
$1,000,000	10,276	<1%
$300,000	2,451,085	13%
$150,000	4,462,196	24%
$75,000	1,785,196	9%
$10,000	194,964	1%

Table 3. Area of land in each price category in the real estate value mapping.

4.4. Conservation suitability

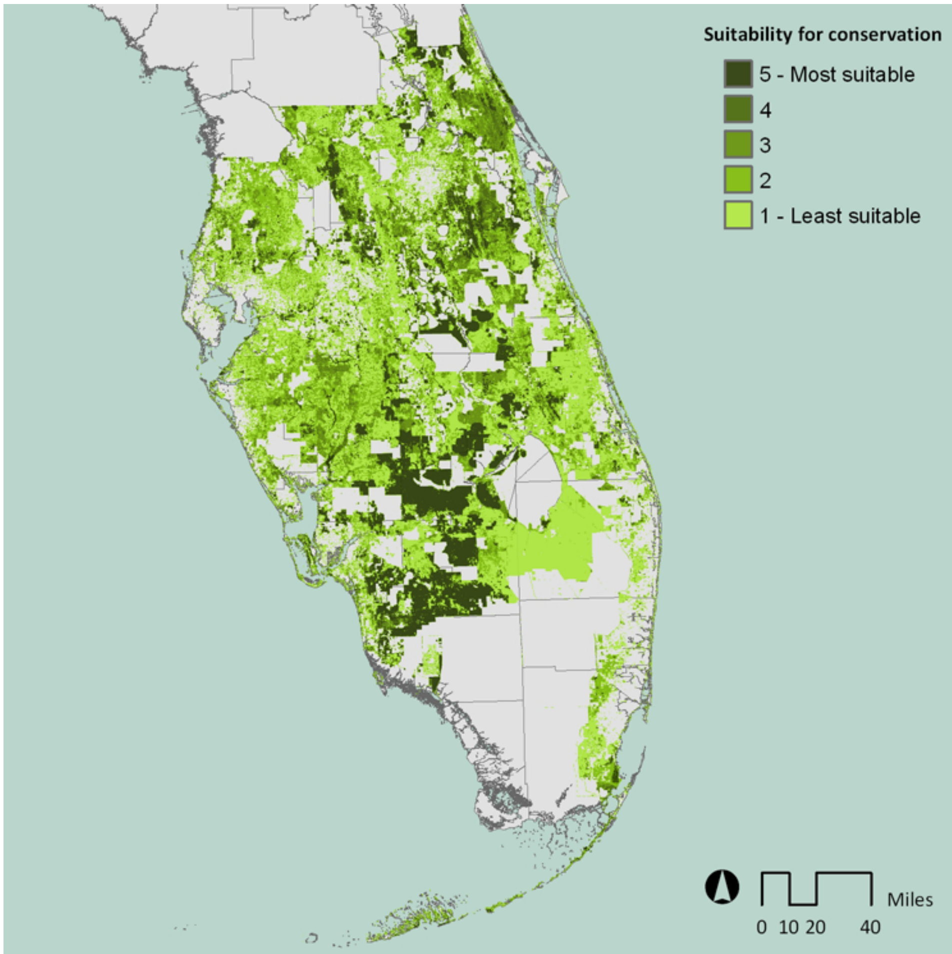


Figure 9. Suitability for conservation

There is over 1.74 million acres of class 5 conservation land (the ranking given to all Strategic Habitat Conservation Areas) located within the study area. This area, though 9% of the whole study area, has an area equal to 29% of all existing conservation lands.

Class	Area (acres)	Percent of study area
5	1,742,132	9%
4	682,758	7%
3	2,018,932	10%
2	3,576,664	18%
1	625,972	3%

Table 4. Area of land in each class of the conservation suitability mapping.

4.5. Real estate value of top conservation land

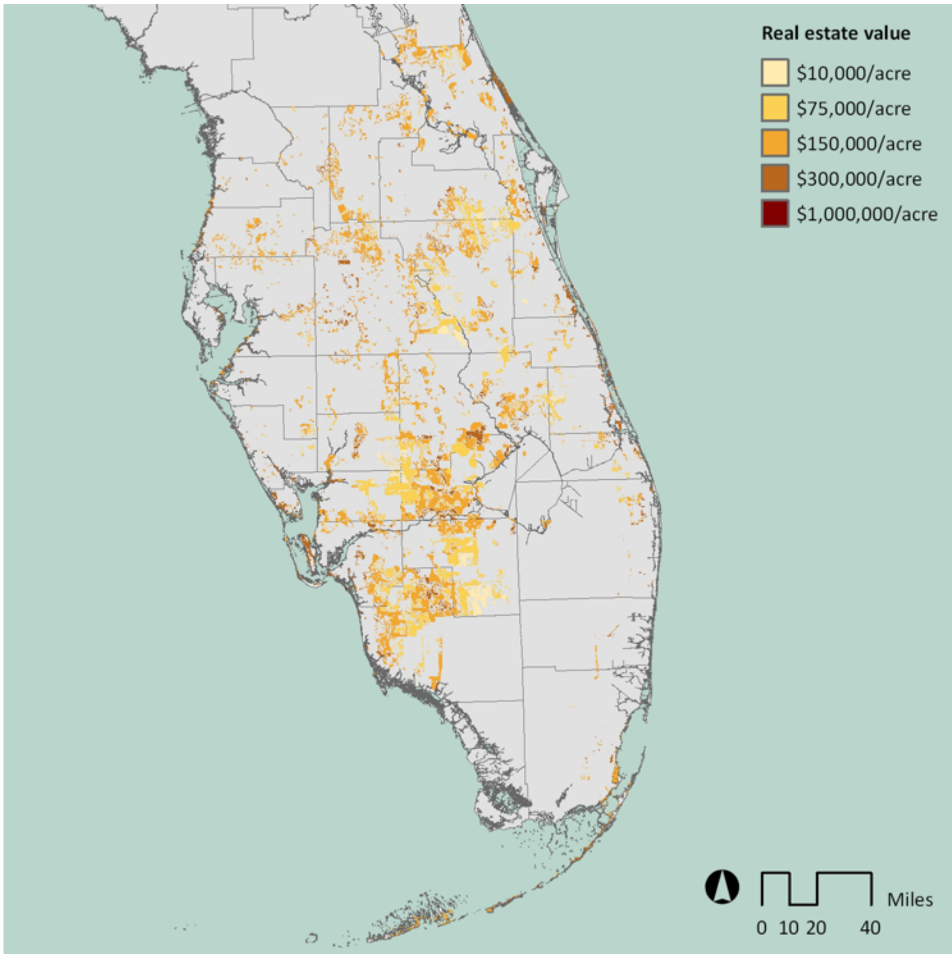


Figure 10. Real estate value of class 5 (best) conservation lands

After multiplying the conservation suitability surface by the real estate value surface, I was able to estimate the costs of land conservation. If all of the highest value land (a total of 1,742,132 acres) were purchased, the total cost of the land would be roughly $263 trillion.

4.6. Future scenario: Fee simple purchase

4.6.1. Conservation land

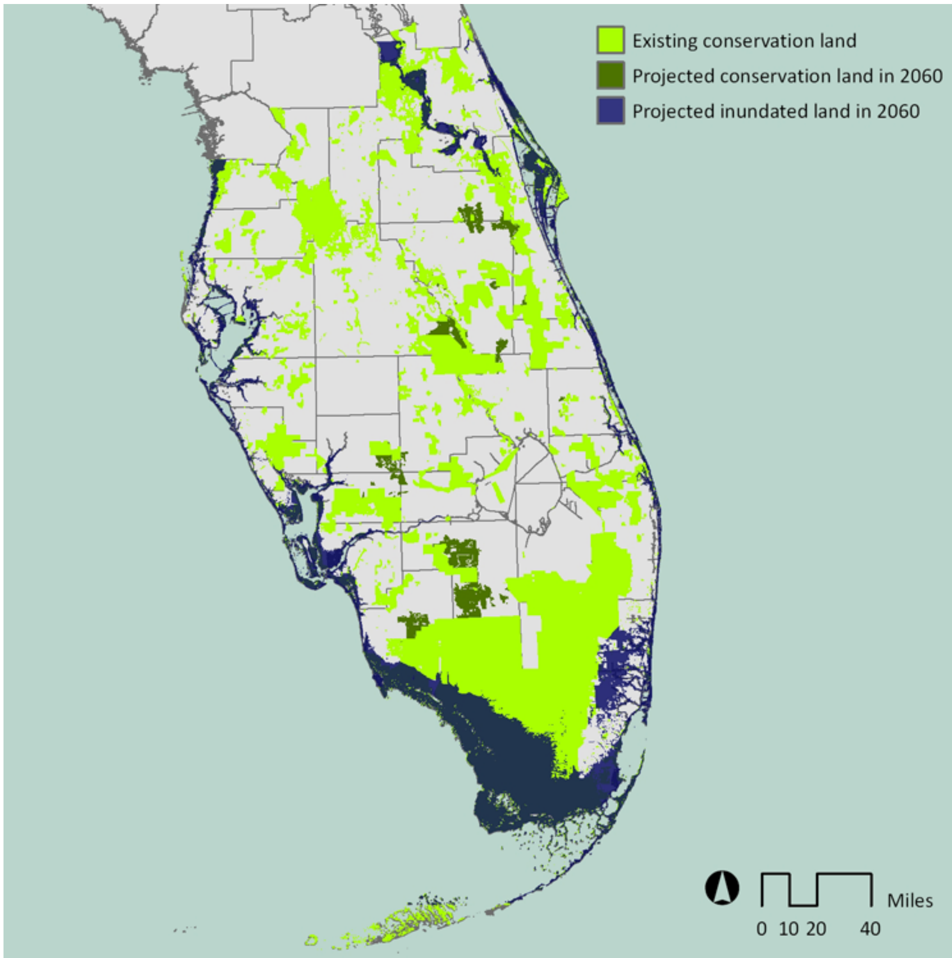


Figure 12. Existing conservation land, projected conservation land by 2060 and inundated land in 2060.

Based on the allocation strategy of purchasing the cheapest, largest patches (greater than 50 acres in size), there is 177,680 acres, 73,972 acres and 75,204 acres added by 2020, 2040 and 2060, respectively. Significantly more land is purchased in the first time step because the allocation is mostly comprised of the cheapest ($10,000/acre) land. By 2040 and 2060 all land must be purchased from the next price category of $75,000/acre.

Year	Acres of conservation	% increase from 2000
2000	6,027,088	
2020	6,204,768	3%
2040	6,278,740	4%
2060	6,353,944	5%
2060, minus inundated land	5,064,884	-16%

Table 5. Total acres of conservation land in 2000 to 2060.

4.6.2. Urban growth

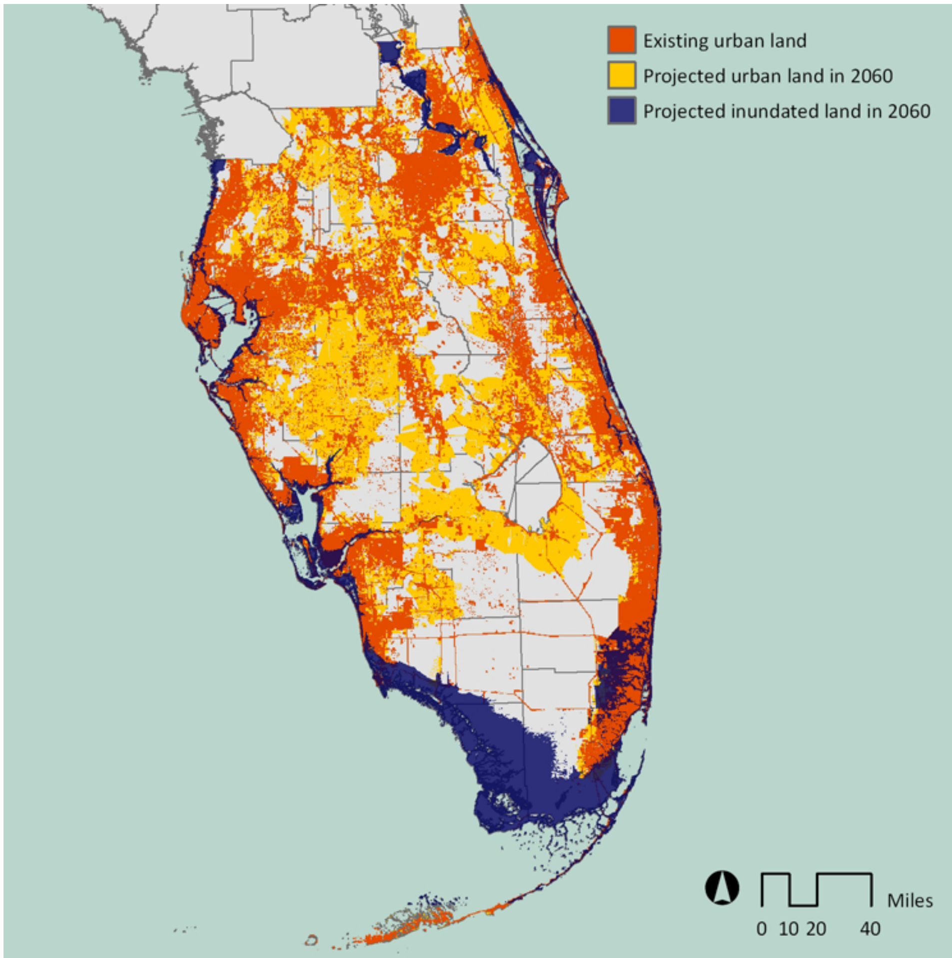


Figure 11. Existing urban land, projected urban land by 2060 and inundated land in 2060.

By 2060, the amount of urban land in south Florida will more than double. All of the class 5, 4 and 3 lands from the urban suitability analysis will be developed. Some of the class 2 lands will be developed. As sea level rise consumes urban land, 75% of the displaced people replaced in the interior, therefore sea level rise almost doubly impacts the undeveloped rural land, as the rural land is both inundated itself and developed by people who were previously living in inundated land.

Year	Acres of urban	% increase from 2000
2000	3,167,584	
2020	5,600,548	77%
2040	7,990,656	152%
2060	10,463,360	230%
2060, minus inundated land	10,160,524	221%

Table 6. Total acres of urban land in 2000 to 2060.

4.6.3. Projected land cover, 2060

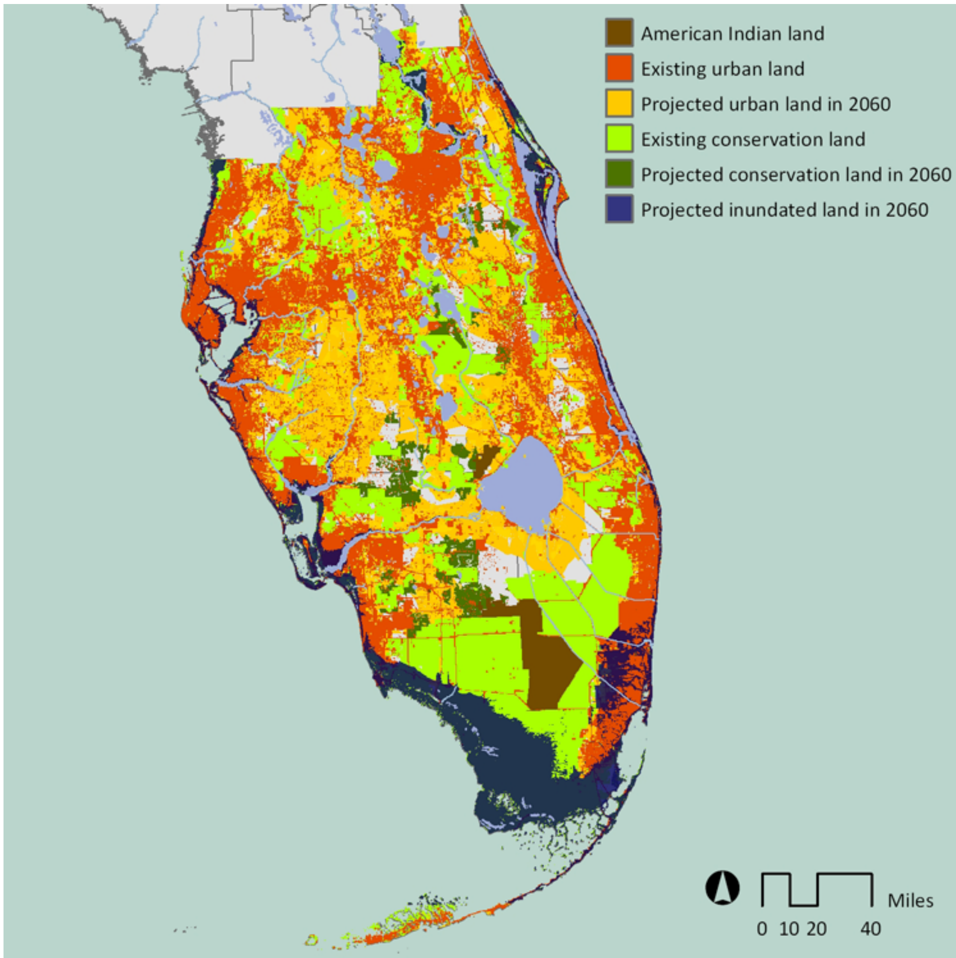


Figure 13. Projected urban land, conserved land and inundated land in 2060.

In the Fee Simple scenario 76% of existing rural lands are converted to new urban land or new conservation land by 2060. Only 24% or existing rural land remains rural.

4.7. Future scenario: Conservation easements

4.7.1. Conservation land

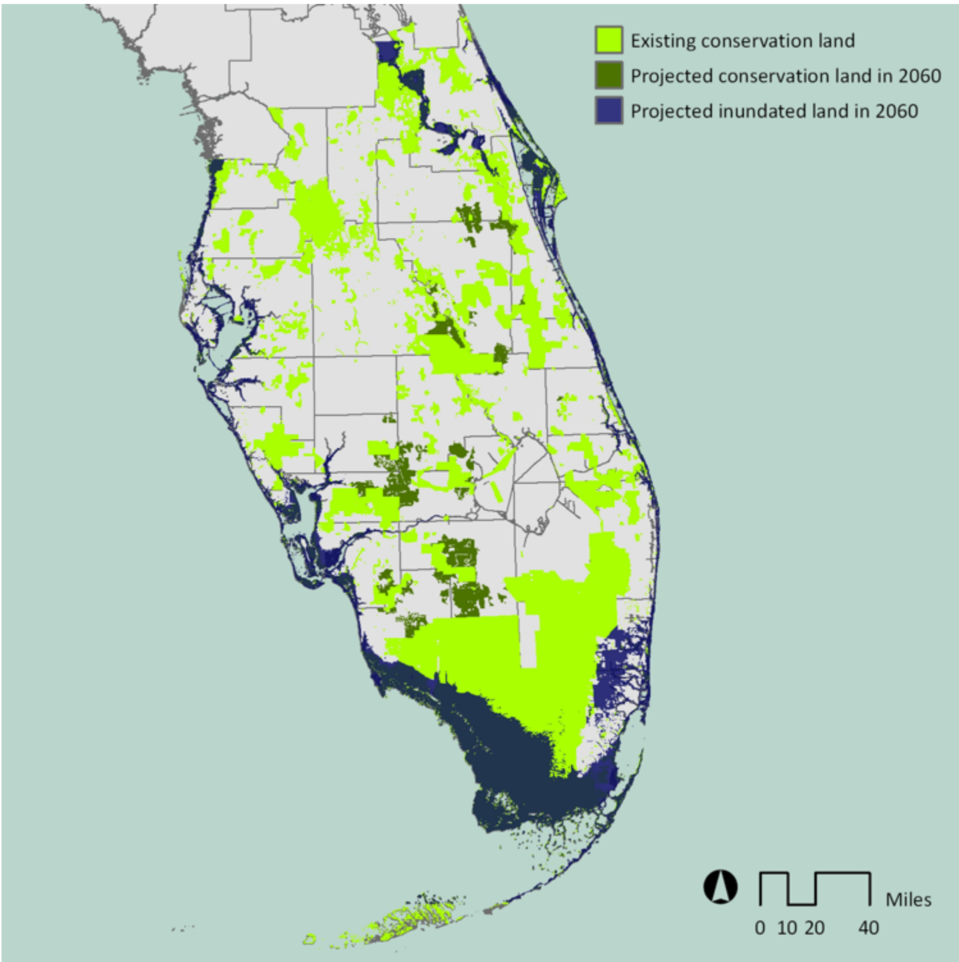


Figure 15. Existing conservation land, projected conservation land by 2060 and inundated land in 2060.

In the conservation easement scenario, there is almost twice as much land conserved per annum as in the fee simple scenario, for an increase of 9% of new conservation land. Nonetheless, due to sea level rise, there is still a net decline in conservation land by 12%.

Year	Acres of conservation	% increase from 2000
2000	6,027,088	
2020	6,289,700	4%
2040	6,440,044	7%
2060	6,566,488	9%
2060, minus inundated land	5,301,388	-12%

Table 7. Total acres of conservation land in 2000 to 2060.

4.7.2. Urban growth

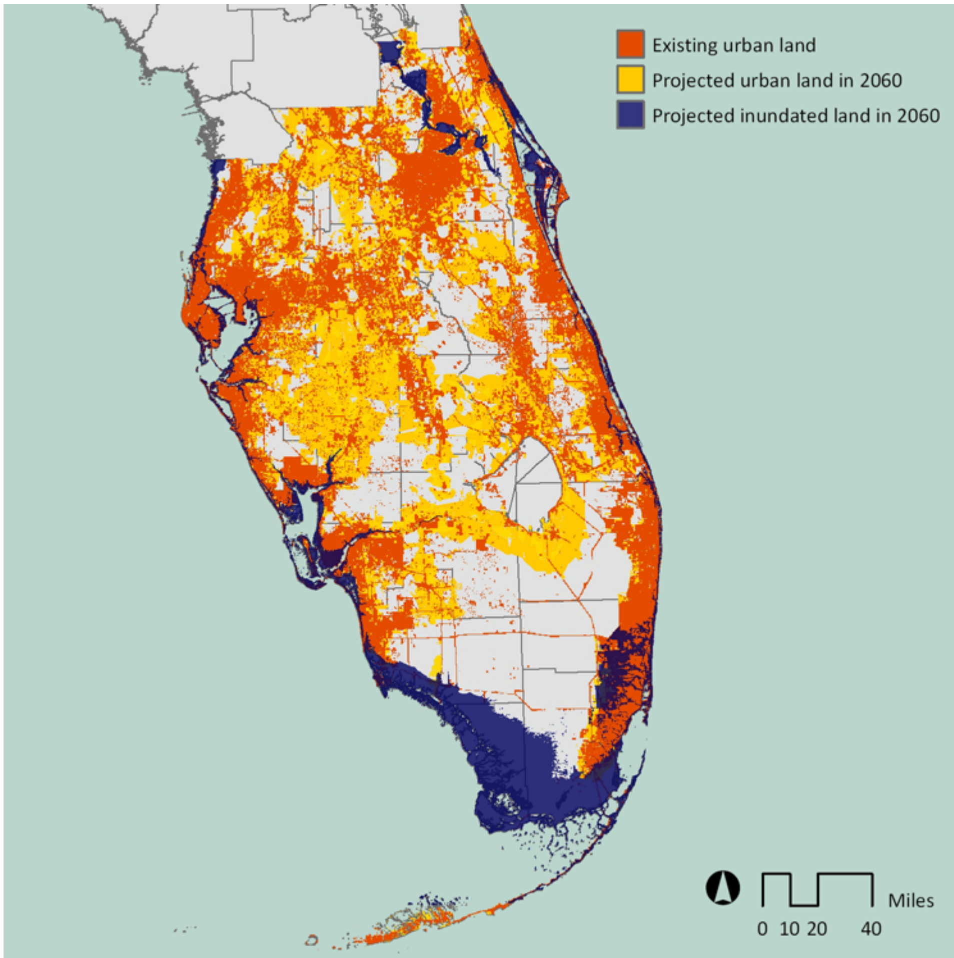


Figure 14. Existing urban land, projected urban land by 2060 and inundated land in 2060.

In the conservation easement scenario, less new urban land is developed than in the fee simple scenario. This is in part because there are 1,924 people that are displaced by conservation in the first scenario, yet stay in place in this scenario. The result is more fully explained as an artifact of the allocation strategy, however. In the conservation easement scenario some of the most desirable, low density land was protected. People who would have been allocated to this land were instead allocated to a less desirable, more densely populated area. The result was a more compact urban form.

Year	Acres of urban	% increase from 2000
2000	3,167,584	
2020	5,441,444	72%
2040	7,795,952	146%
2060	10,262,268	224%
2060, minus inundated land	9,957,832	214%

Table 8. Total acres of urban land in 2000 to 2060.

4.7.3. Projected land cover, 2060

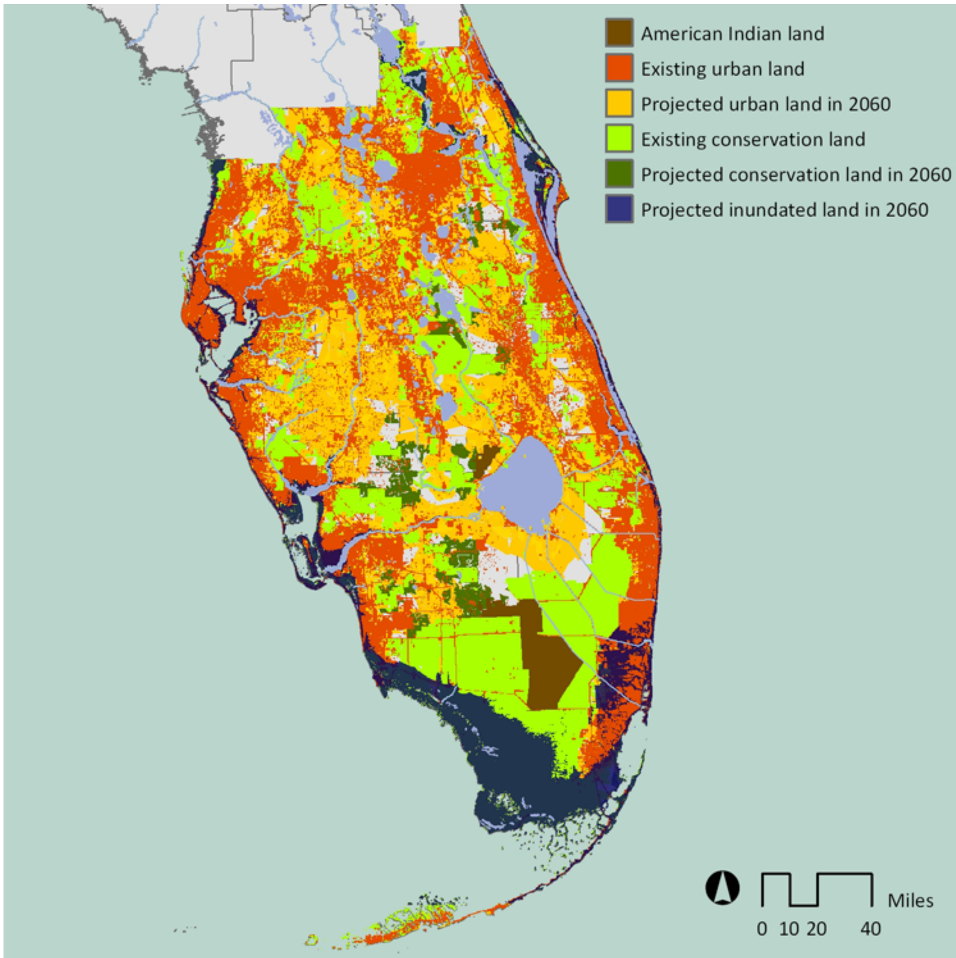


Figure 16. Projected urban land, conserved land and inundated land in 2060.

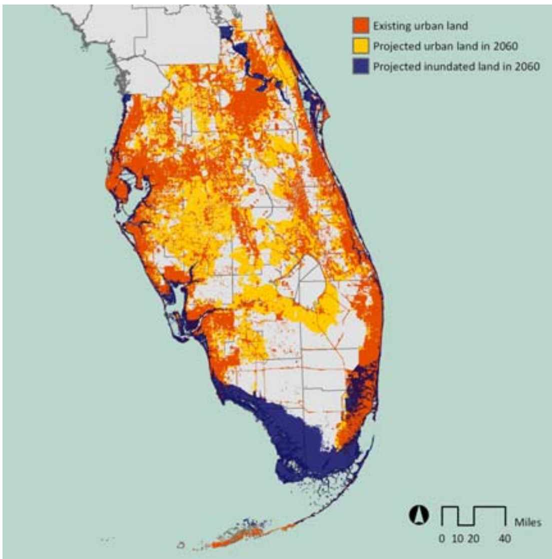
In this scenario, as land is urbanized, 61% of rural lands are converted to urban uses. Twenty nine percent of rural land remains rural, with 6% under conservation easement and 33% unchanged.

5. Conclusions

5.1. Analysis of results

The following provides side-by-side analysis of the preceding results.

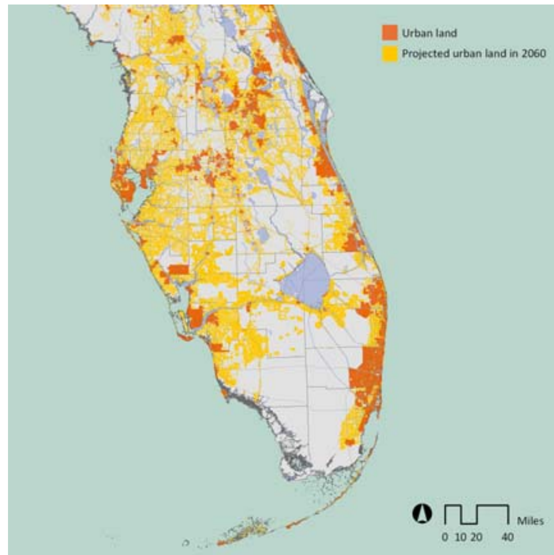
5.1.1. Fee simple purchase versus Florida 2060



Fee simple purchase

STUDY AREA:

- 3 million acres existing urban
- 23 million new people (2007-2060)
- 1 million displaced people
- 7 million acres new urban land
- 230% increase from 2000



Florida 2060

ALL OF FLORIDA:

- 6 million acres existing urban
- 18 million new people (2005-2060)
- 7 million acres new urban land
- 116% increase from 2000

STUDY AREA:

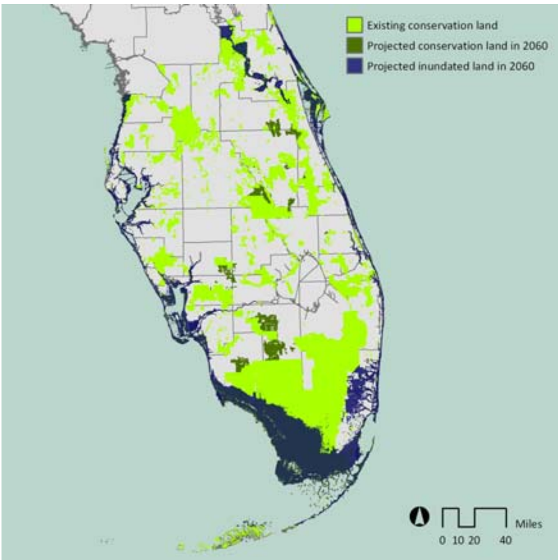
- 4 million acres new urban land

In comparing the new urban land in this thesis against the benchmark *Florida 2060* study, it is notable that there is significantly more urbanization in this thesis. This is due to differences in assumed population projections and build-out densities. In regard to population projections, it is interesting to note that though the spatial extent of this thesis is more limited than the spatial extent of *Florida 2060*, the number of people that it was necessary to accommodate in this study was greater than in *Florida 2060* by 6 million. This is likely due to changes in the BEBR population projections, as this study relies on data that is 2 years more recent than *Florida 2060*. In regard to build-out densities, in this study I identify more land as existing urban. I tested my demarcation of urban against satellite imagery and it appeared from the imagery that my assumption of urban as greater than 1 person per acre was generally strong. Since I am allocating this urban fringe density into the adjacent non-urban land, however, my allocation creates a broad suburban condition. As a result of this allocation strategy I create a lower average density than in *Florida 2060*. I believe that the low density suburban condition is likely to be the trend of development, however, unless there are major policy interventions.

Aside from the differences in total urban area, the two maps show surprising similarity in the projected build-out pattern, including urbanization along the South rim of Lake Okeechobee, along the Caloosahatchee and on the inland West.

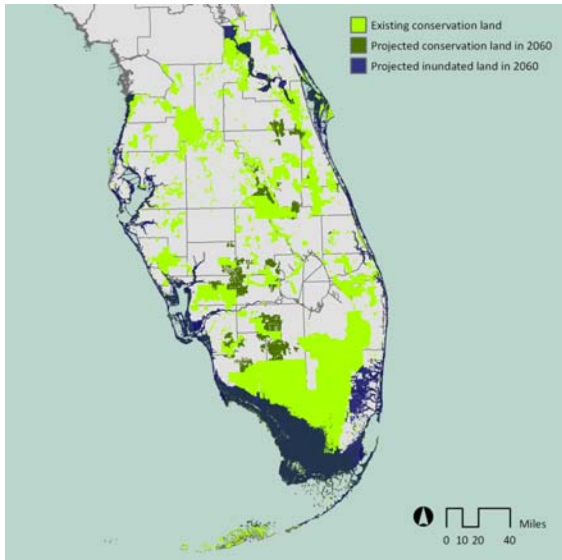
While a full sensitivity analysis was outside the scope of this study, the comparison of these two datasets indicates that the quantity of urban land is highly sensitive to population size and build-out density. The comparison also indicates, however, that the general pattern of urbanization is largely insensitive to these same factors.

5.1.2. Conservation land: fee simple versus conservation easements



Fee simple purchase

2060:
- 5,064,884 acres
- 5% increase in new land holdings
- 19% class 5 land protected
- 16% total loss of conservation land after sea level rise, despite new holdings



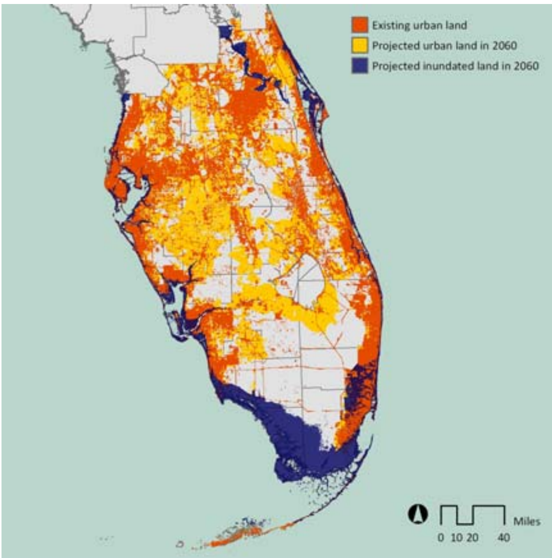
Conservation easement

2060:
- 5,301,388 acres
- 9% increase in new land holdings
- 32% class 5 land protected
- 12% total loss of conservation land after sea level rise, despite new holdings

In comparing the fee simple and conservation easement scenarios, it is clear that conservation easements can protect significantly more land than fee simple purchase. Yet, it is also clear that the rate of land acquisition in both scenarios is slower than the rate of urbanization and loss of land to sea level rise.

Assuming that *all* of the class 5 land (Strategic Habitat Conservation Areas) must be protected for the persistence of the species of the Everglades (Cox and Kautz 2000), both scenarios will likely have substantial negative impacts on south Florida's flora and fauna.

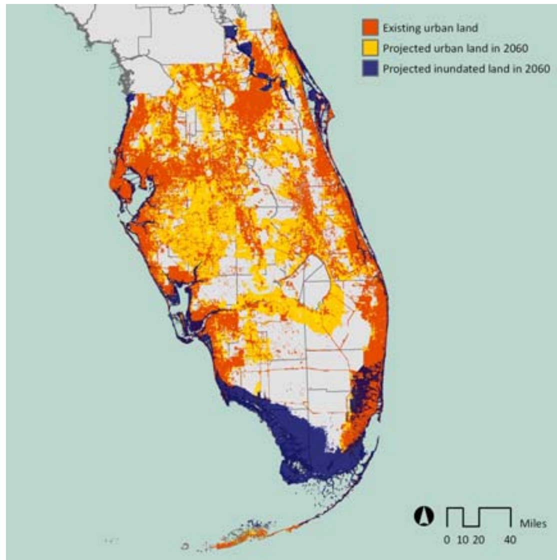
5.1.3. Urban land: fee simple versus easements



Fee simple purchase

2060

- 10,160,524 acres urban land
- 221% increase from 2000



Conservation easement

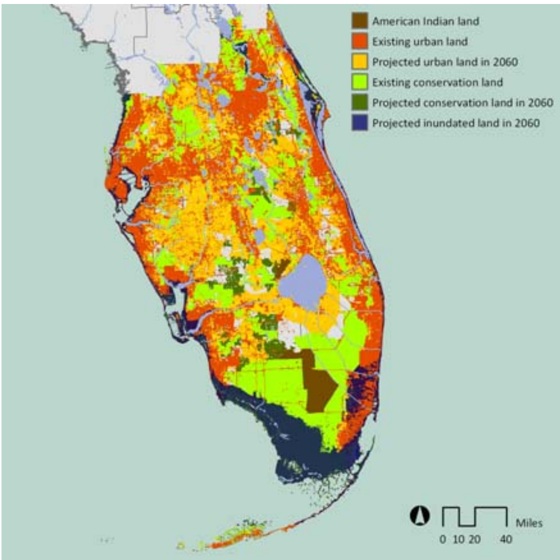
2060

- 9,957,832 acres urban land
- 214% increase from 2000

As described earlier, it is likely that the sizeable difference between the quantities of urban land in the two scenarios is largely an artifact of my allocation strategy. In the conservation easement scenario, land that was attractive for low-density urbanization was conserved. Instead, people were allocated into areas that are less attractive and more densely populated. In actuality, it may be that people move to areas that are even less attractive, but of similar density.

Nonetheless, it is important to underscore that the conservation easement scenario protects attractive rural land that would otherwise develop at low-density urban.

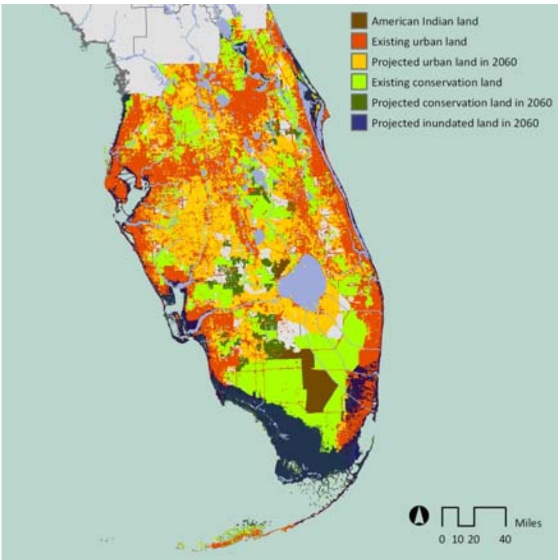
5.1.4. Projected land cover: fee simple versus easements



Fee simple purchase

2060

- 76% of rural lands are converted to new urban or conservation land
- 24 % remains rural



Conservation easement

2060

- 61% of rural lands are converted to new urban
- 6% are put under easement
- 33% remains rural

The change in the overall land cover in south Florida between now and 2060 is striking, regardless of the land protection scenario. In the fee simple scenario, less than one quarter of the current rural land remains in rural land use. The conservation easement scenario preserves much more rural land, but still only 39% remains in a working rural landscape. As Florida is a major provider of beef, citrus, sugar and other agricultural products to the whole of the US, the loss of these rural lands will have far-reaching economic impacts.

Conservation easements will likely be critical in implementing land protection in south Florida. This is because, in addition to protecting important habitat, easements dually maintain the region's rural landscape. In contrast, fee simple purchase adds conservation to urbanization and sea level rise as factors that displace people from rural lands. Instead of generating an antagonistic relationship between conservation and working rural, it may be possible to build support of large scale conservation by teaming with constituencies concerned with rural land preservation.

5.2. Federally-backed conservation easements

As demonstrated in both scenarios, unless there are significant changes in human migration and build-out densities in south Florida, the quantity of urban land in the study area will more than triple by 2060. Simultaneously, the amount of protected land will decline by over 10%. The amount of rural land – replaced by urban land or conservation land – will decline as much as 76%. With substantially more urban land, less conservation land, and much less rural land, the ecological and social landscape of south Florida will dramatically change.

Between the two scenarios explored in this thesis, conservation easements protect substantially more land than fee simple purchase. By securing 32% of class 5 land instead of 19%, easements provide greater security for species. Yet, easements are still unable to capture the full extent of class 5 land with the current $300 million per year budget, making it clear that no matter the mechanism of conveying protection, the current budget is inadequate for protection of the ecosystem in the face of urbanization and sea level rise.

If fee simple purchase remains the status quo method of protection, in order to protect all of the most important, class 5 lands, it will cost approximately $263 trillion (or roughly $5.26 trillion per annum, if distributed over the next 50 years). This budget is roughly five orders of magnitude larger than the existing conservation budget. The resources necessary to scale up current conservation are sufficiently large that it is clear such a conservation project cannot be accomplished by the state alone.

Major federal intervention, on the order of the protection conveyed in the mid-1900s with the establishment of Everglades National Park, Big Cypress National Preserve and Biscayne Bay National Park, is needed again. Because the ecological, social and political landscape in Florida has changed significantly over the last 50 years, however, it is unlikely that the next major federal intervention should look the same as the last one.

I propose a new federal conservation initiative that relies on conservation easements and distributed land management as a means of conveying protection. This differs from the fee simple purchasing and centralized management that is the primary mechanism of protection used by the federal government. The strength of conservation easements as a land acquisition strategy is demonstrated by the results of the modeling in this thesis and is outlined below:

- *Conservation easements increase purchasing power* by as much as 200%, since the cost of conveying protection is as little as half of a traditional fee simple land purchases (Lee 2009). Because of increased purchasing power, in the conservation easement scenario it was possible to protect an almost 60,000 more acres of land than in the Fee Simple scenario.

- *Conservation easements decrease management costs* by keeping the existing land managers (i.e., the current owners of the land) in place. This allows for a distributed system of land management where the people who live and work on the land continue their practices.

- *Conservation easements preserve rural character* by allowing ranchers and farmers to continue working their land. This is a major growth management goal in Florida, as demonstrated by the Rural Land Stewardship Area Program. Florida recognizes the threat of low density, "ranchette" subdivision and is seeking to preserve the working character of the existing rural lands. A federally-supported conservation easement program could accomplish this state objective alongside its ecological objectives.

- *Conservation easements are less socially disruptive* because no one is displaced from their land. This differs from fee simple purchasing, where the occupant must relocate. As shown in the fee simple model, approximately 2,000 people were displaced by conservation land purchasing. Should a large scale conservation intervention occur, even more people would be displaced. If a significant number of people were displaced – even if they were fairly compensated – there is a potential for social backlash.

As a mechanism for land protection, easements have the potential to significantly increase the amount of conserved land and provide the capacity to manage the land, all while meeting state objectives of preserving rural land. Furthermore, because easements do not displace any current residents, it is possible that a large scale conservation easement program would prove more politically expedient than fee simple purchasing. There are two major barriers for instituting such a program, however: there is not a precedent of the federal government guaranteeing conservation easements and there is not an institution in place that has the capacity to monitor a large array of easements.

5.3. Easement guarantee and monitoring

While there is not a long standing historic precedent of the federal government guaranteeing conservation easements, there is reason to believe that it possible to change strategies. Firstly, there are some instances, such as the case of mitigation banking in Florida, where a deed restriction is backed over time. Secondly, there is no requirement, per the mandates of each land owning federal conservation organization, that they take full ownership of each piece of land under their protection. Thirdly, there are several existing private lands divisions within federal agencies that help landowners with private land management (e.g., the Conservation Reserve Program). Fourthly, given the challenge of climate change and urbanization, it is no longer possible to fulfill the mission statements of the conservation-minded federal organizations with the existing methods of protection. For example, NPS's mission to "*conserve the scenery* *and the natural and historic objects and the wild life [inside the park] and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations"* will require management and protection far beyond the park boundaries.

I suggest that conservation easements become the de facto method of federal land protection. In this vision, each conservation-oriented, landowning federal agency, such as NPS, FWS, BLM, USFS, negotiates the terms of a conservation easement that meets their agency objectives and the needs of the landowner. After the deed restriction is purchased from the landowner, the land owner manages the land consistently with the easement agreement.

After the conservation easement agreement is purchased, it is necessary to monitor the property to ensure that land management is in compliance with the conservation easement agreement. Monitoring requires a substantial amount of decentralized manpower and agencies do not currently have the necessary staffing and distribution to undertake a large scale monitoring effort. In order to ensure that land is properly monitored over time, it will be necessary to formally institutionalize monitoring within the Department of Interior.

I suggest the formation of a new agency within the Department of Interior that is primarily tasked with the enforcement of conservation easement agreements. Additionally, the monitoring agency will keep track of restoration efforts across separate land holdings, help landowners coordinate, and penalize landowners that are not maintaining high quality habitat on their land. While the overall organization of monitoring would be centralized in one agency, the actual land monitors would be distributed regionally. It may be possible for the land monitors to be housed within cooperative extension programs, for example. While a monitoring agency is a departure from current practice, it is critical in scaling up land protection beyond current direct management capacity levels.

5.4. Building support

Methods of land protection and management in the United States have not significantly evolved on a federal level since the mid-1900s. The agencies within the Department of the Interior have been more or less operating with the same resources for over 50 years. The current environmental challenges of urbanization and climate change are so substantial and sufficiently widespread, however, that the old tools for protection are no longer adequate. The Department of Interior must respond to these imminent challenges with a new land protection strategy.

In order to build the momentum and support necessary to change the long standing tradition of federal protection through fee simple purchase, it will be necessary to garner the support of a wide range of constituents. The proposed program of conservation easements has the potential to do so because flexibility in easement agreements can allow easements to meet the needs of many different constituents. Following is a list of general potential program supporters:

Constituency	**Interest**
Environmentalists	Preserving/restoring species habitat
Outdoor recreationalists	Maintaining quality of experience
Small ranchers/farmers	Maintaining way of life
Agribusiness	Maximizing and diversifying revenue sources
Water managers	Storing and treating stormwater and runoff
Rural land owners	Maintaining way of life
Tourism officials	Ensuring quality of tourist attractions

Table 9. List of potential supporting constituencies and their primary interest in an easement-based conservation program.

Combined, the seven groups listed above may be able to generate sufficient lobbying power and exposure across all political parties to successfully advocate for a new land purchasing paradigm based on conservation easements.

5.5. Land use regulation

Although conservation easements convey numerous advantages over fee simple purchase, in this study, if all class 5 conservation lands were protected with easements the total cost would still be $132 trillion. Though much less than the fee simple price of $263 trillion, $132 trillion remains substantial. If the entire federal budget[5] were spent on Everglades conservation easements alone, it would take over 36 years to protect all of the needed land. Once the challenge of conveying protection is considered cumulatively for all for all of the conservation areas throughout the US, the needed funding becomes simply unrealistic.

Therefore, while market-based mechanisms of protection are attractive and can be useful in certain cases, it will not be possible to purchase every development right for threatened, critical land across the county. Instead, it will be necessary to identify the areas that are at greatest risk and then consider how conservation easements can be combined with land use controls to convey protection. While land use controls that limit development rights without compensation are not easy or politically palatable, they will be necessary.

There is constant pressure on municipalities to allow subdivision of existing rural lands and expansion of urban services. Land owners wish to maximize the economic value of their properties and municipalities seek to secure or expand tax revenue. Rural subdivision and development, however, combined with the unachievable budget

[5] Assumed constant at $3.6 trillion per year, the budget for FY 2009-2010

needed to purchase development rights will lead to an ongoing expansion of urbanization that incurs great environmental costs. The challenge remains of identifying where development rights should be purchased, where land use controls should be implemented and where new urban growth should be accommodated.

6. Future research

There are several aspects of this thesis that merit future study, particularly within the modeled scenarios and in relation to establishing a new monitoring agency. Known areas of future research are outlined below.

6.1. Everglades modeling

All of the major assumptions outlined in the methodology of this study can be – and should be – challenged.

1. *Sensitivity analysis*
   A detailed analysis of the sensitivity of the model to each of the assumptions should be calculated.

2. *Projected population*
   Further study should consider the efficacy of the 2008 release of population projections used in this study. New population studies recently released include 2008 estimated populations. It is likely this new release of data will reflect the current downturn in growth and migration in Florida, unlike the data on which this study is based. Such changes in projected population could substantially impact the quantity of projected urban land.

3. *Projected density*
   Further study should carefully explore the density of development at which subdivision and redevelopment becomes unlikely. This would be a good starting point for defining "urban" land, which I presumed to be greater than or equal to 1 person per acre in this study.

   Secondly, it is important to consider the impact of allocating adjacent densities over the non-urban lands and assuming those densities remain unchanged over time. It is possible that densities within existing urban areas will increase if there is economic incentive to do so. It is also possible that new clusters of density would begin to form.

4. *Sea level rise*
   Future study will require ongoing revision of the sea level rise approximations used in this thesis. In particular, as down-scaled models of global climate change are developed, it will likely be possible to provide a better local prediction of sea level rise. Additionally, this thesis linearly divides rise over time, even though it is unlikely the changes will be linear. Future study will likely reveal finer time steps in expected rises.

5. *Patch size*

In the conservation suitability allocation, the minimum patch size was established at 50 acres. Future study should reconsider this minimum patch size and determine whether, in a conservation easement scenario, patch size should influence the ability to take on a deed restriction.

6. *Real estate dynamics*
   Firstly, one of the major assumptions behind the purchasing strategy is that for each time step conservation land is secured first and urban land is determined afterwards. This is a considerable simplification relative to transaction-based real estate models.

7. *Real estate value*
   This study makes several simplifications in real estate transactions. Is it correct now? Are those 5 major classes at all accurate across the state? All money-based transactions stay proportional over time. Real estate values stay proportional over time. Secondly, the absolute and relative transaction costs of fee simple purchase and conservation easements should be more deeply explored.

8. *Displacement*
   In this study, it is grossly assumed that 75% of the people who are displaced by sea level rise or conservation remain in south Florida. This figure should be further refined.

9. *Urban allocation: tiebreaking strategy*
   Further study should include individual density preferences. Do people have a clear density preference, and they choose to live at that density regardless of the general urban attractiveness? Or does urban attractiveness define desirability, and then people are willing to live at a denser build-out to be located within the attractive urban area?

6.2. Federal land protection initiative

Several questions remain on the feasibility of establishing a new mechanism of land protection and the supporting monitoring agency. Following is a sample of questions that will be necessary to answer in the next phase of research.

1. *What are the political barriers to instituting a new agency? How might these barriers be overcome?*

2. *What are the costs associated with establishing a new agency? In what timeframe will these costs be recovered?*

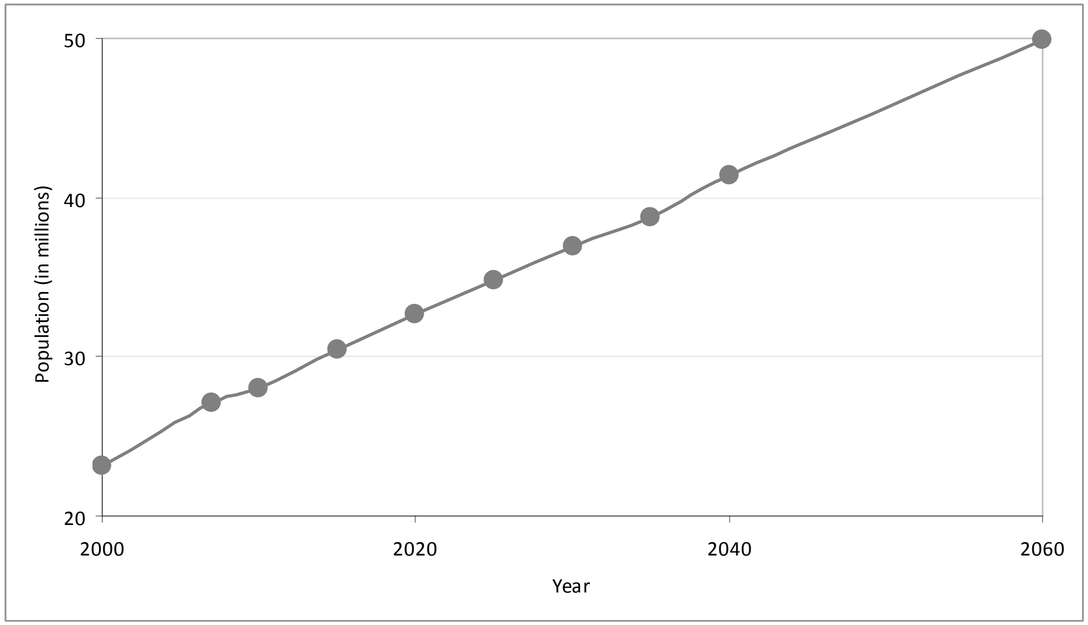
3. *How can constituencies be engaged?*

Appendix 1: County population projections

Following is the county-by-bounty growth data used in this study. University of Florida's Bureau of Business and Economic Research provides Low, Medium and High growth projections. This thesis relies on the Medium projections shown below.

County	Census	Estimate		Projections, April 1					
	April 1, 2000	April 1, 2007		2010	2015	2020	2025	2030	2035
BREVARD	476,230	552,109		568,500	612,700	653,300	692,500	729,000	762,500
BROWARD	1,623,018	1,765,707		1,806,300	1,915,800	2,016,400	2,113,400	2,203,900	2,286,700
CHARLOTTE	141,627	164,584		169,700	183,300	195,900	208,000	219,300	229,600
COLLIER	251,377	333,858		353,900	406,300	455,300	503,300	548,900	591,200
DESOTO	32,209	33,983		34,700	37,500	39,200	40,700	42,100	43,300
GLADES	10,576	11,055		11,600	12,100	12,600	13,000	13,400	13,800
HARDEE	26,938	27,520		27,700	28,300	28,700	29,200	29,600	30,000
HENDRY	36,210	39,651		40,800	43,800	46,700	49,400	52,000	54,300
HERNANDO	130,802	162,193		169,100	187,800	205,100	221,900	237,600	252,200
HIGHLANDS	87,366	98,727		101,600	109,400	116,500	123,400	129,800	135,600
HILLSBOROUGH	998,948	1,192,861		1,234,900	1,346,600	1,449,900	1,549,900	1,643,400	1,729,300
INDIAN RIVER	112,947	139,757		145,800	162,000	176,900	191,500	205,200	217,800
LAKE	210,527	286,499		303,500	347,900	389,500	430,200	468,700	504,500
LEE	440,888	615,741		654,600	756,700	852,000	945,300	1,033,500	1,115,500
MANATEE	264,002	315,890		327,500	358,400	387,000	414,600	440,500	464,300
MARTIN	126,731	143,737		147,900	158,900	169,000	178,800	187,900	196,300
MIAMI-DADE	2,253,779	2,462,292		2,512,300	2,645,500	2,768,300	2,886,800	2,997,200	3,098,300

MONROE	79,589	78,987		78,700	77,800	77,000	76,300	75,500	74,900
OKEECHOBEE	35,910	39,030		39,700	41,500	43,100	44,700	46,200	47,500
ORANGE	896,344	1,105,603		1,154,200	1,282,200	1,401,200	1,517,100	1,626,200	1,727,000
OSCEOLA	172,493	266,123		287,500	343,200	395,500	446,800	495,700	541,200
PALM BEACH	1,131,191	1,295,033		1,335,500	1,444,000	1,543,800	1,640,000	1,729,500	1,811,300
PASCO	344,768	434,425		454,200	507,400	556,600	604,500	649,500	691,000
PINELLAS	921,495	944,199		950,300	966,900	982,200	997,000	1,010,900	1,023,700
POLK	483,924	581,058		602,500	660,500	713,900	765,500	813,800	858,200
ST. LUCIE	192,695	271,961		288,900	335,000	378,400	420,600	460,300	497,200
SARASOTA	325,961	387,461		400,600	436,100	468,800	500,300	529,800	556,700
SEMINOLE	365,199	425,698		439,200	475,400	508,700	540,900	570,900	598,400
SUMTER	53,345	89,771		97,400	117,400	136,100	154,500	172,100	188,500
VOLUSIA	443,343	508,014		522,500	561,000	596,500	630,700	662,700	691,900
STUDY AREA	**12,670,432**	**14,773,527**		**15,261,600**	**16,561,400**	**17,764,100**	**18,930,800**	**20,025,100**	**21,032,700**



Population growth in south Florida over time. Last official census occurred in 2000, an estimated population is plotted in 2007. All projects from 2010 – 2035 were provided by BEBR. Projections at 2040 and 2060 were extrapolated with a best fit line.

Appendix 2: Model diagram

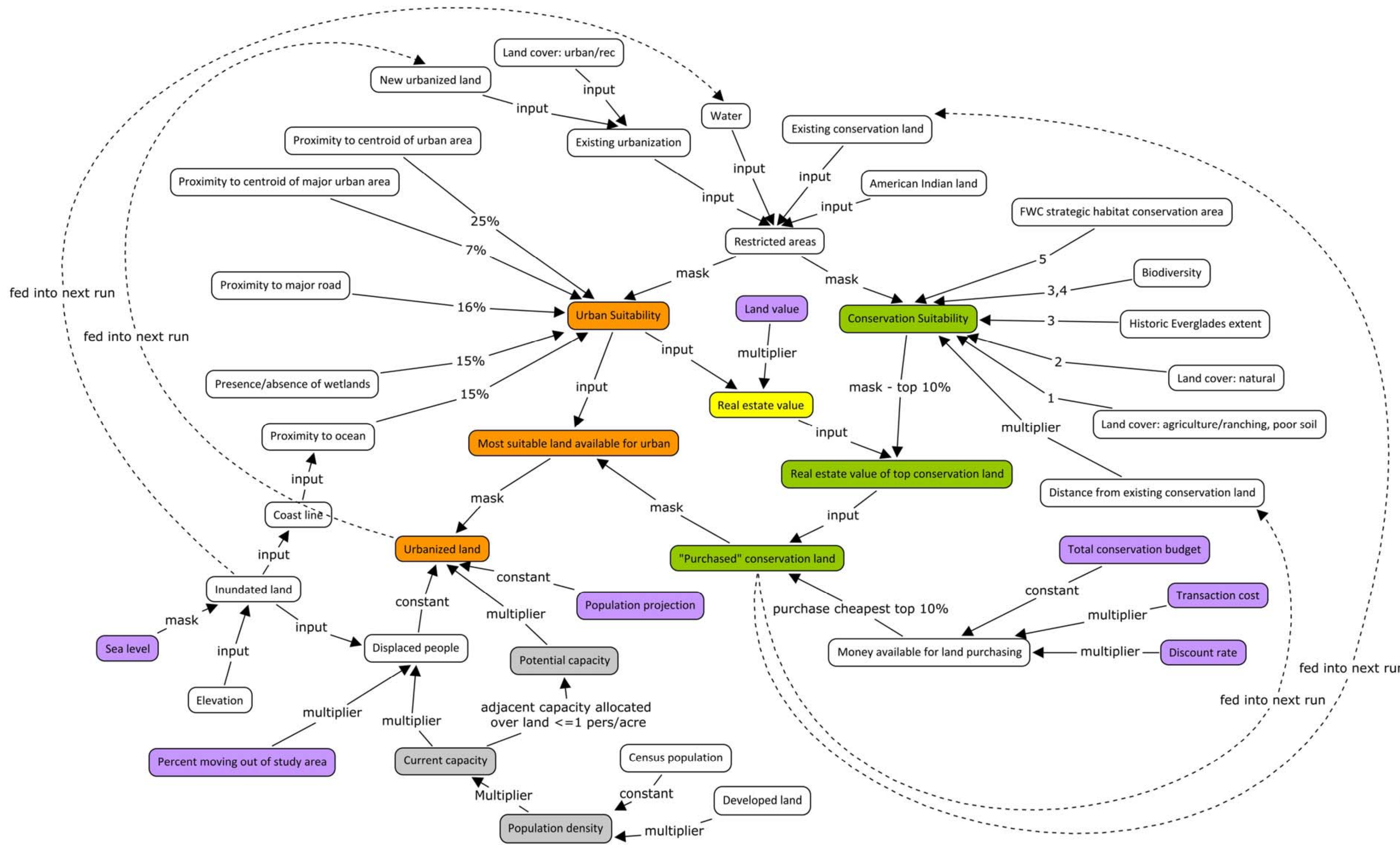


Diagram of the modeling process used in this thesis. Purple boxes are parameters. Boxes without fill are existing, publicly available data or simple derivates of that data. Orange boxes are products of the urban suitability analysis. Green boxes are products of the conservation suitability analysis. Yellow boxes are real estate valuations. Grey boxes are population density studies.

Appendix 3: Input parameters

PARAMETER VALUES

Sea level rise	
2020	0.3 m
2040	0.7 m
2060	1.1 m
Projected population	
2020	9562611
2040	8689867
2060	8527911
Total conservation budget	$300,000,000
Transaction cost multiplier	6%
Land discount rate (for conservation easements)	50%
Percent of displaced people moving out of study area	25%
Land Value (based on Urban Suitability)	
Class 5	$1,000,000/ac
Class 4	$300,000/ac
Class 3	$150,000/ac
Class 2	$75,000/ac
Class 1	$10,000/ac

Appendix 4: Overlay weighting

URBAN SUITABILITY ANALYSIS

Ranked on a scale of 1 to 5, where 5 is most attractive for urban development

Distance from city/town	**33%**
<8000m	5
8000-12000m	4
12000-16000m	3
16000-20000m	2
>20000m	1

Distance from major road	**22%**
<1000m	5
1000-2000m	4
2000-4000m	3
4000-8000m	2
>80000m	1

Distance from ocean	**15%**
Under water	Restricted
<500m	5
500-1000m	4
1000-4000m	3
4000-8000m	2
>8000m	1

Wetlands	**15%**
Presence	1
Absence	5
Inland water	Restricted

Distance from major city (pop > 50,000)	**15%**
<8000m	5
8000-12000m	4
12000-16000m	3
16000-20000m	2
>20000m	1

CONSERVATION SUITABILITY ANALYSIS

Ranked on a scale of 1 to 5, where 5 is most attractive for conservation

Strategic Habitat Conservation Area	
Presence	5

Biodiversity	
5 or more focal species	4
3-4 focal species	3

Land cover	
Natural (undeveloped)	3
Agriculture	2
Other	1

Appendix 5: GIS data layer summary

File name	Description	Producer	Distributer	Year
amindianlands_2008	American Indian land	GeoPlan	FGDL	2008
cenblk##	Census block data by county (##)	US Census Bureau	FGDL	2000
cities_feb04	Centroids for cities and towns of FL	National Atlas of the United States	FGDL	2004
fl2060growth	Growth projections from *Florida 2060*study	GeoPlan	FGDL	2006
florida_managed_areas-fnai	Land managed for conservation	Florida Natural Areas Inventory	FGDL	2005
gap_lcov##	Land cover data by county (##)	Florida Cooperative Fish and Wildlife Research Unit	FGDL	2000
Gfchot	Biodiversity hot spots	Florida Fish and Wildlife Conservation Commission	FGDL	1989
majrds_jul08	All major roads in FL (based on functional classification)	Florida Department of Transportation	FGDL	2008
Shca	Strategic habitat conservation areas	Florida Fish and Wildlife Conservation Commission	FGDL	2000
south_florida-dem	Digital Elevation Model of south Florida	USGS	USFWS	Unknown

*FGDL: Florida Geographic Data Library, http://www.fgdl.org/

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